August 1954

NUCLEONICS

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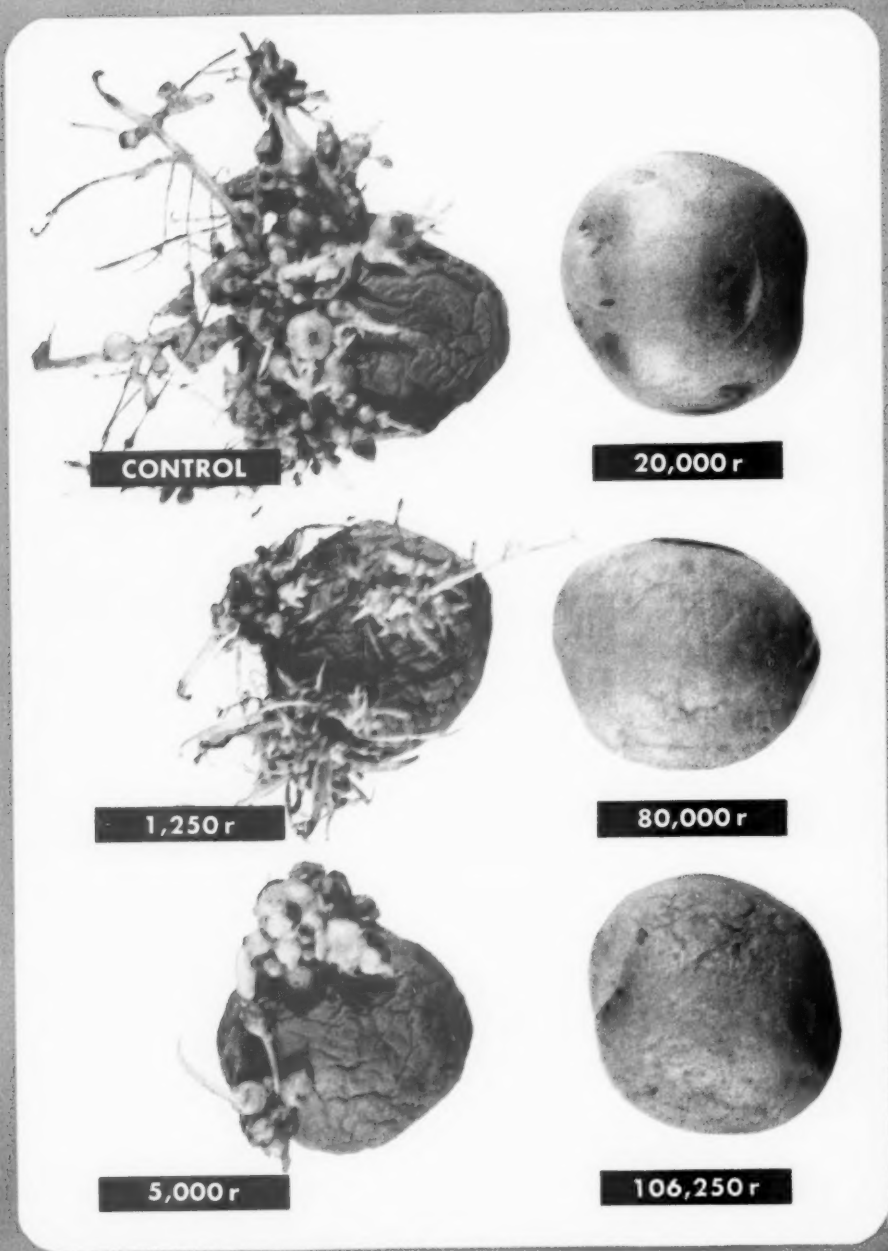

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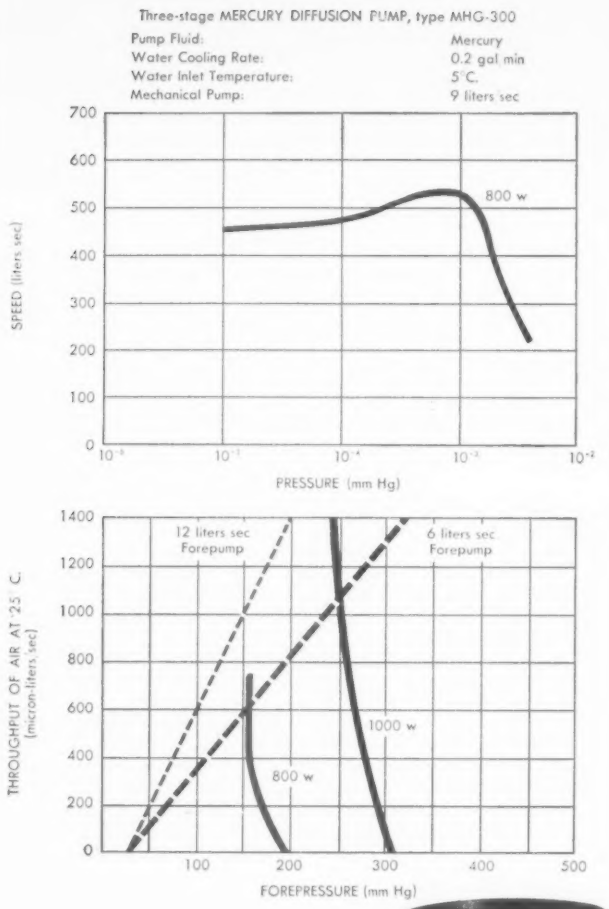

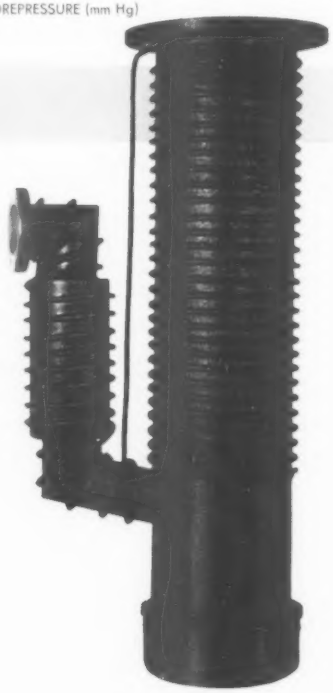

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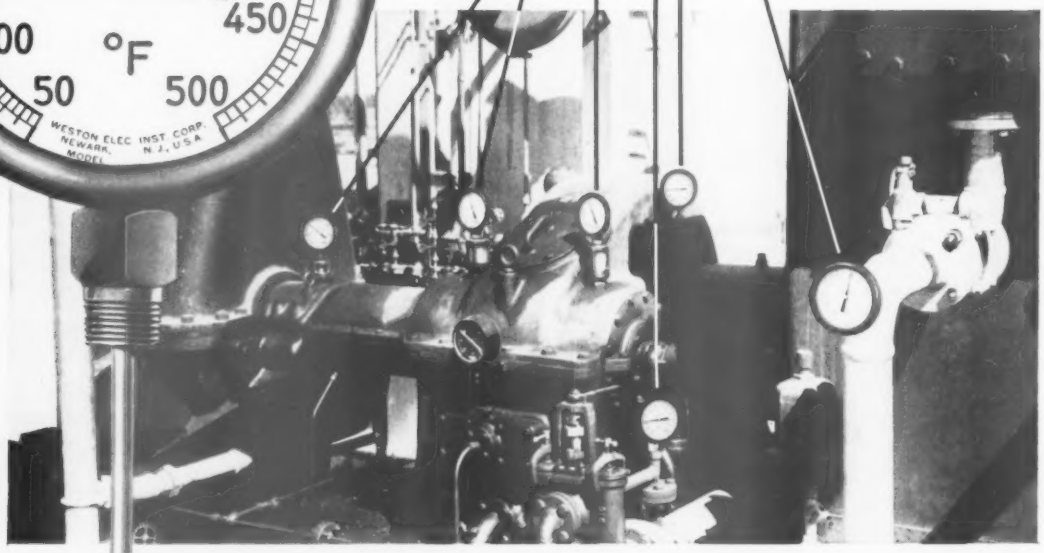

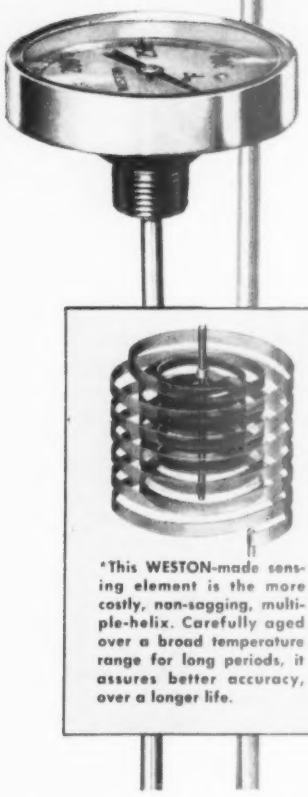

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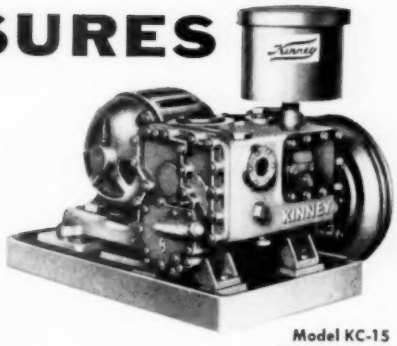

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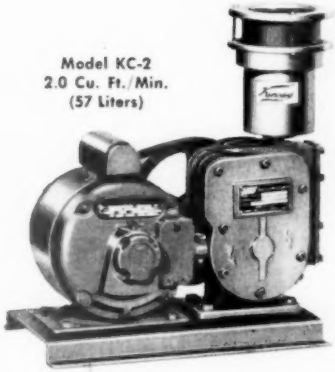

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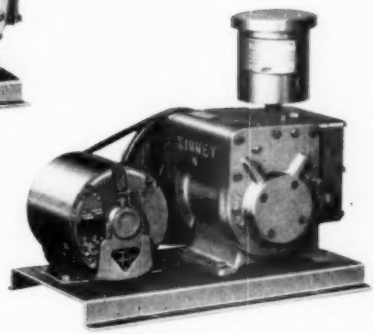

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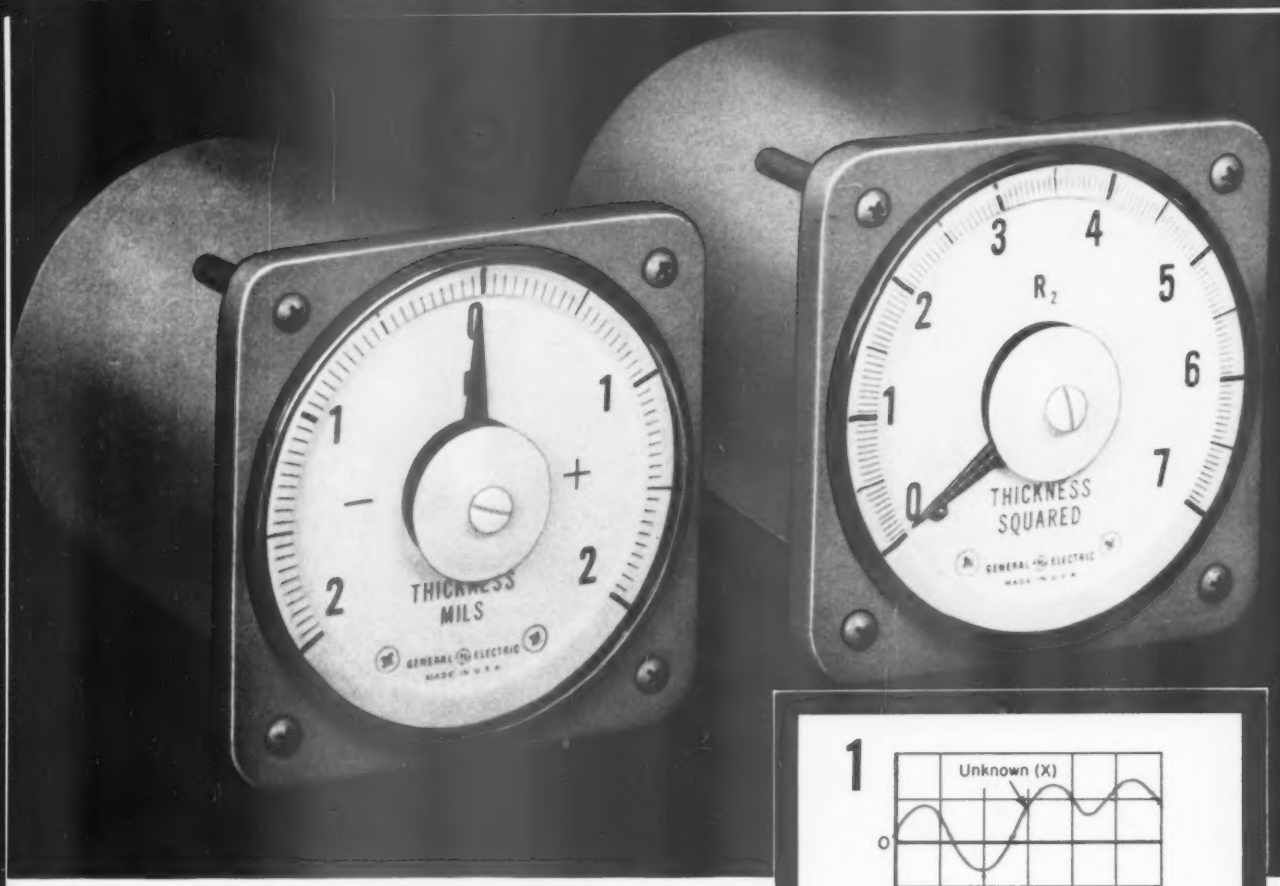

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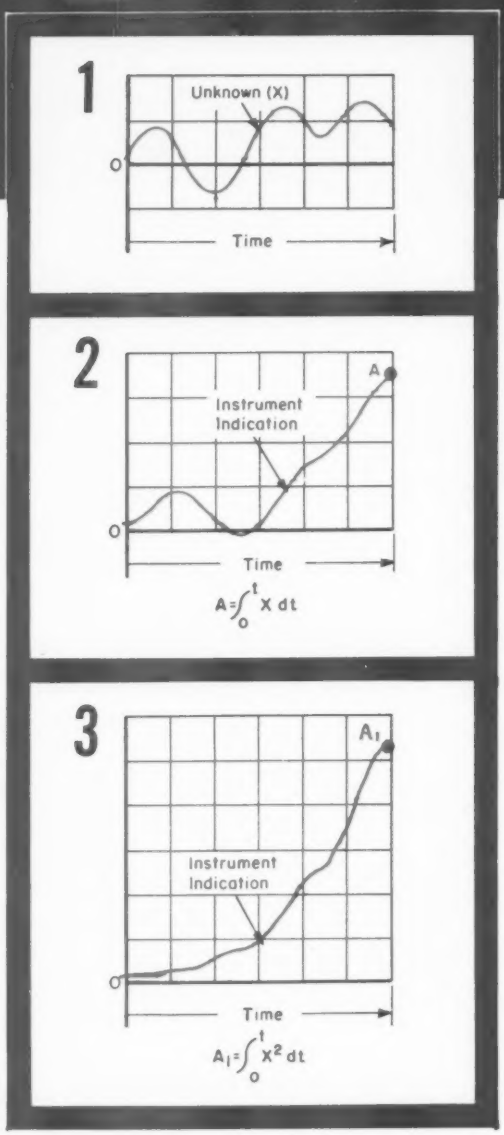


LATE NEWS

Compiled by NUCLEONICS August 5 . . . for publication August 9

Revision of Law

Industry gets its first big chance to enter the atomic power field on an experimental and commercial basis. Overhaul of the 1946 McMahon Atomic Energy Act drew nationwide attention during the 13-day Senate hassle over it. The revisions—which amounted to a complete revamping of all existing atomic legislation—sailed through the House in less than two days.

The long, bitter Senate debate on the measure hardly hit at the three major aims of the bill: (1) To chart the Federal role in all atomic energy matters. (2) To foster industrial development of nuclear power and other peacetime aspects of atomic energy. (3) To permit broader exchange and transfer of information and materials on atomic energy with friendly foreign nations.

Main Senate controversy came over President Eisenhower's directive to AEC to shift part of its Paducah, Ky., power requirements from Tennessee Valley Authority to private utilities. When public-power Senators failed to sidetrack this directive, they tried writing their views into various sections of the bill.

Main differences between House and Senate versions of the bill were on patents and electric-power issues. To iron out these differences the two versions were sent to a House-Senate conference committee made up of ten of the top members of the Joint Congressional Committee on Atomic Energy.

Major issue to be resolved is over patents. Conferees must find an acceptable solution to House-Senate differences on this one. The Senate tightened requirements for compulsory licensing of peacetime atomic power patents by extending the mandatory licensing period of basic patents from five to ten years after enactment of the new law. The House deleted the compulsory licensing provisions, except that inventions conceived while the inventor was employed by the Government are to become public property.

Only other sizeable House-Senate controversy comes on public versus private power issues. These had to be ironed out:

(1) Senate voted to authorize AEC to go into the electric power business, building atomic power plants as money is provided by Congress. House action would expressly forbid this. (2) Senate would give preference in issuance of atomic power-plant licenses to public bodies and rural electric cooperatives in high-cost power areas. House voted down the same sort of provision. (3) Senate voted to create an AEC division of civilian Application. The House turned down this proposition.

After three days of discussion, status of conference committee action on Aug. 5 was: Difference on patents section continued despite several compromise attempts. On AEC going into power business, this would be permitted only so far as experimental "demonstration" plants are concerned. Conferees also spelled out fact that other Federal agencies are eligible to apply for licenses to build and operate atomic power plants if they can gain Congressional authorization and funds.

•

AEC Progress Report

Developments in U. S. atomic energy program in last six months, as reported in 16th Semiannual Report of AEC, include:

Production of uranium attained record levels. There are now 530 U. S. uranium mines; 15 contain more than 100,000 tons of ore.

Capital investment in atomic energy production plant facilities is now at $5.7 billion.

AEC predicts industry will spend $5 million in '54 on reactor activities.

University of Michigan has received preliminary AEC approval for its 1-megawatt research reactor.

A 1–4 megawatt swimming pool reactor (known as "Omega West Reactor") will replace the recently dismantled plutonium fast reactor at Los Alamos.

AEC predicts AEC and contractor operations personnel (for production, re-

search and development services) will increase to and level off at 82,000 by 1956.

Four 324-ft towers have been completed at Oak Ridge for experiments with aircraft reactor shields. Protective shielding for the crew and a test reactor with its own shielding can be suspended from these towers well above ground, simulating shielding conditions of an airplane in flight. It is expected that air and ground scattering effects will be determined and divided shields (NU, June '54, p. 85) will be optimized.

•

Reactor "Runaway" The first known instance in this country where a reactor has been made to "run away" occurred at the National Reactor Testing Station, Idaho Falls, Idaho, on July 22. Argonne National Laboratory, in continuing its "borax" tests on a boiling-water reactor, pulled out all stops in testing the stability and safety of the reactor. In 1953, it was expected that under such conditions the reactor core would melt and allow the escape of radioactive fission products. This did not happen then. In the July 22 test, although the reactor vessel did give way and fission products were released, the inherent safety of the system was proved again because of the extremes to which the reactor had to be pushed.

The AEC announcement on this development said: "During an experiment at AEC's National Reactor Testing Station this morning, there was a large instantaneous release of energy accompanied by some radioactivity. This experiment, of a type for which the testing station was established, was at a site removed from the permanent installations. There was no overexposure of personnel to radioactivity and no hazards resulted outside of the immediate vicinity of the experiment."

•

Australian Reactor Plans are being accelerated to build the first nuclear power station in Australia. Latest proposals are aimed at incorporating such a station in the $1-billion Snowy Mountains Hydroelectric Scheme.

•

"Reactor of the Year" AEC proposed last month that, until nuclear power becomes competitive, electric utilities combine with AEC each year to build the "reactor of the year," the plant that would provide the greatest technological advance at minimum cost to government. The utility would provide an "amount of money equal to the cost of a conventional plant for the location in question, while AEC, as part of its research and development expenses, would finance the balance. . . . Government would also purchase byproduct plutonium at a fair price."

It is reported that this approach may be applied to the General Electric proposal that a dual-purpose plant be built at Hanford. Private utilities in the northwest have been considering a cooperative effort, with the power produced to be fed into the northwest power grid.

•

Swedish Reactor The first Swedish nuclear reactor began operations on July 13 at 1 watt. It will shortly be run at 100 kw.

•

Dutch Reactor Funds The Lower Chamber of the Dutch Parliament has approved a $2.2-million State contribution toward the building of a $7.4-million experimental reactor in The Netherlands.

•

Industry Growth AEC predicts present savings of $100-million per year to industry through use of radioisotopes will jump to $1-billion per year by 1964. Radiation instrument business will grow, according to AEC, from $20-million in 1952 to $35-million in 1956. Although 300 U. S. companies are now using radioisotope thickness gages, it is estimated that only 5% of the market has been tapped.

NUCLEONICS AUGUST, 1954

Jerome D. Luntz, *Editor*

Freedom and Progress

EXAMINATION OF WORLDWIDE ADVANCES in science and technology made in recent years would produce the conclusion that civilization has "progressed." A direct product of this progress is the increased ability of nations to make war. And security, it is felt, comes to those nations that have the greatest military might. A concomitant of this philosophy is that technological secrecy—the withholding from unauthorized persons of specified scientific or technological information or devices—enhances this security.

Virtually no one objected to the complete secrecy that blanketed the atomic bomb project during the war. In the first several years after the war, there were, however, considerable outcries against the stultifying effects of secrecy. But then, when this had no effect, people adjusted to living in a society where secrecy was commonplace. It is difficult to argue against it because of the intangibles involved and because those who do so are accused of "selling out to the enemy."

One of the best expositions of the pitfalls of secrecy that we have come across was made by Lloyd V. Berkner, president, Associated Universities, Inc., at the International Nuclear Engineering Congress in Ann Arbor on June 24. He called for a "deep and searching inquiry into the restrictions on technological information" and suggested that the following six factors be considered:

1 **In a democracy it is absolutely impossible to cloak a large undertaking in full security.** It is like trying to hide an elephant under a paper hat. There are only two alternatives: (a) an absolute Iron Curtain of the Russian type around the country, with full control of *all* individuals, products and information, or (b) application of security to a small but sensitive area of technology in a very restricted sense. Moreover, we stand to lose most when we do try to cloak a large undertaking, for we acquire neither the security of technological information *nor* the security of progress.

2 **Widespread security of technological information is inimical to the security of progress, which is based on well-developed weapons and men trained to use them effectively.** In the absence of an Iron Curtain, security of information must depend on compartmentalization of knowledge. Very little compartmentalization is needed to destroy scientific progress or to restrict training and limit tactical familiarity with new weapons. Therefore, if we are to have security based on progress, the information to be restricted must be sharply defined. If, eventually, we should have to fight, we must decide now whether it is to be with effective weapons about which an enemy knows a great deal, or with pieces of paper about which he knows nothing.

3 **The regulations necessary to the maintenance of secrecy in large areas of technological information condition the scientist to avoid the conception of militarily valuable ideas.** Although responsible men resist such conditioning, the resulting frustrations inevitably reduce his creative effectiveness. Furthermore, excessive security prevents some of the world's most creative men from contributing to our national welfare.

4 **The secrecy of technological information is incompatible with the public policy function of a democracy.** In our elective system, there is no certainty that policy-making officials will possess the competence required for wise decisions or even understand what elements of information are important. Moreover, even assuming the wisdom of policy-making officials, sound policy results from the careful examination of the facts by the people of our nation and depends upon their diverse training and interests. Secrecy prevents the discussion necessary to such examination, and compartmentalization prevents proper evaluation even by trained specialists. The public press is the source of the intelligence that *really* most influences our policy-makers and military leaders. No adequate substitute can be found in internal intelligence, because information unevaluated by public debate lacks the convincing quality resulting from public review.

5 **Widespread secrecy of technological information keeps the public ignorant of the adjustments it must make in the face of technological change.** Failure to make adjustments to an evolving environment has in the past led to the extinction of a species. Yet the desire to make such adjustments can emerge only from a sound understanding of the alternatives as they become clear from public debate, or from the ultimate disaster into which society unwittingly blunders.

6 **Widespread technological secrecy with respect to national capabilities may lead the enemy to underestimate our power, and encourage him in irresponsible adventures leading to war.** There are many examples of this, though none can be proved absolutely, since events never conjoin in the same way in history.

Development of the Second French Reactor

By integrating the technical chronology with the philosophies underlying construction of the Saclay reactor, the director of the project paints the best available picture of the French advance towards nuclear power

By L. KOWARSKI
*Commissariat à l'Energie Atomique, Paris, France**

THE FRENCH AEC started its activity early in 1946. Its first goal was to produce a low-power reactor sufficient to exhibit the nuclear chain reaction in its simplest form and free from all preoccupation as to what to do with its energy output. This first reactor, called Zoe, came to life at the end of 1948; this was, for French reactor designers, the end of the first stage and the beginning of the next.

The *second* reactor, in the opinion of its originators, had to supply a substantial amount of scientific and operating data that would provide the designers a base on which to face, in a concrete way, the problem of nuclear power on an industrial scale. Behavior of metallic uranium and other materials under irradiation, maximum temperatures tolerable inside a reactor, effect of cooling pipes on the nuclear process and vice versa—none of these questions could be answered properly without actual observation on an experimental prototype in which as much power as possible was developed in a minimum possible volume. Whatever ambitions we could cherish to go far in this direction had to be weighed in these early days of 1949 against two hard facts of life: the necessity for speed and the total absence of technical information from abroad. (The first Anglo-American declassifications of reactor information did not become effective until late in 1950.)

Choice of Reactor Design

The French production of metallic uranium was just getting into its stride. It was reasonably certain enough would be available in time to fuel a heavy-water pile, but hardly enough to envisage a graphite-moderated reactor, which would require at least ten times more metal. For cooling, a choice had to be made between four variants.

1. Circulation of heavy water in bulk. This system, already well known from CP-3 (Argonne National Lab.), was later on used in JEEP (Oslo) and SLEEP (Stockholm). It raises no serious mechanical difficulties and can be built quickly. The power yield per ton of uranium is of the order of 100, possibly 200 kw. The temperature stays appreciably below 100° C. Generally speaking, operating conditions differ radically from those foreseen as likely in an industrial nuclear plant.

2. Circulation of low-pressure air along uranium rods. Compared to 1, this method promises no important gain in power yield per ton (a factor 2 or so), but it is of vastly greater interest as an introduction to industrial applications. Low-pressure air cooling has been used in America and especially in Britain in connection with graphite-moderated reactors containing vast masses of uranium and reaching well into the two-figure megawatt region.

3. Circulation of compressed gas along the rods. It was natural to think of air first; since it is advisable to remove ingredients that, at a high temperature and under irradiation, may become corrosive (oxygen) or highly radioactive (argon), one comes naturally to the idea of using nitrogen. Other gases (in particular CO_2) were envisaged later on.

Compressed gas is a much more efficient coolant than a low-pressure one. The only limit is that imposed by the mechanical strength of pipes that can be lodged conveniently in a reactor.

This cooling method can evolve directly into an economically interesting way of producing motive power. A prototype of this description is, however, obviously more difficult to build than a low-pressure one.

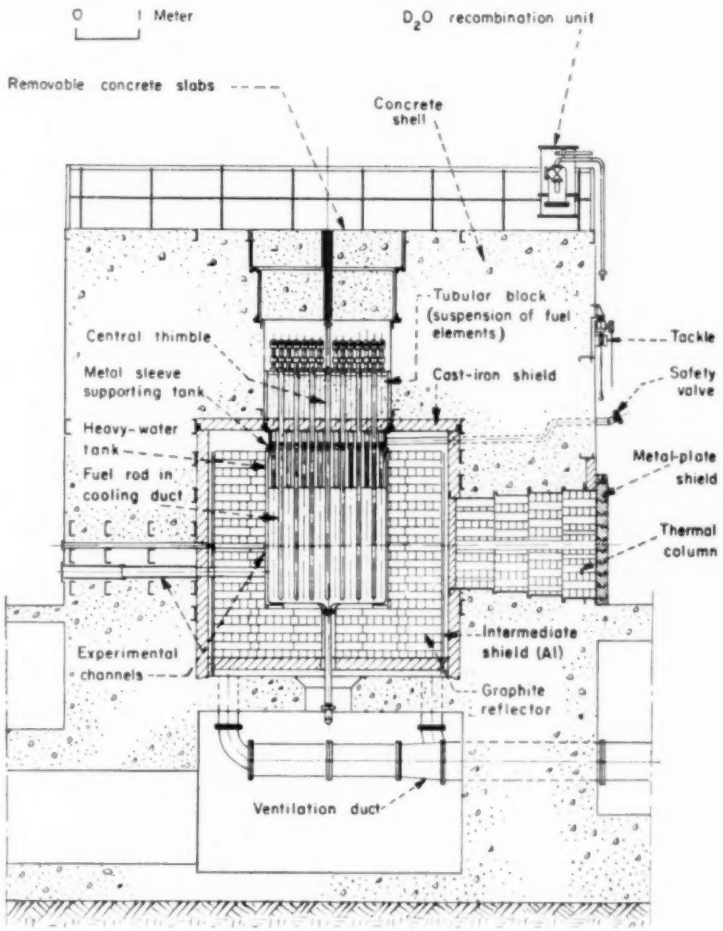
4. Circulation, under pressure, of a liquid along the rods. As long as natural uranium is the only fuel available, the choice of liquid is practically limited to natural and heavy water; the former is cheap, but the latter absorbs no neutrons and therefore requires a smaller quantity of uranium.

Water cooling, as used in the U. S. and Canada in conjunction with natural uranium, permits the highest rates of power extraction per ton of uranium. Its difficulties, notably metallurgy and precision mechanics, are many.

The four preliminary projects were

* PRESENT ADDRESS: European Council for Nuclear Research, Geneva, Switzerland.

The Saclay Reactor: Construction and Operation



CONSTRUCTION of reactor is shown by cross section. Criticality can be achieved with about $5\frac{3}{4}$ metric tons of heavy water in reactor tank; in practice about $6\frac{1}{2}$ tons are used to maintain a reserve reactivity. Total uranium mass of slightly under 3 metric tons is divided among 136 rods. Each sheathed rod is suspended inside aluminum tube about twice rod's diameter; annular space surrounding rod is divided by another tube into two concentric tubular ducts. Compressed gas travels downwards in outer duct, enters inner duct at lower end of rod and returns upwards, in inner duct, in direct contact with rod sheath. During downward journey gas helps cool heavy water, from which it is then separated by only one thickness of aluminum tubing. When going upwards, gas picks up heat from uranium rod. Each of the 136 double ducts is individually gastight; reactor tank itself is not built for high pressures. Cadmium plates move vertically between tank and reflector for control; two safety rods can be dropped along tubular channels into central part of reactor

EXPERIMENTAL FACILITIES (three channels, thermal column, and central thimble shown) are not as numerous as is desirable in a laboratory reactor, since this reactor is primarily a cooling experiment. 21 horizontal channels, 10 to 14 cm square, lead up to tank wall through biological shields and reflector; 37 vertical channels are located just outside graphite reflector; one central thimble, 6 cm in diameter, reaches reactor core. Single fuel elements can be replaced by more complicated structures such as uranium sleeves for fast-neutron irradiation, or experimental cooling devices

examined in August, 1949, by the High Commissioner and his advisors. The third variant was chosen because of its importance for future reactor technology; its power yield was judged reasonably high, taking into account the level of specialized knowledge (in particular as regards metallurgy) reached at that time in France. We were well aware of the interest previously shown by American and British specialists in compressed-gas cooling, and we knew that, in the conditions of their own atomic development, the building of a reactor of this type was provisionally postponed. We did *not* know that this provisional state of things lasted well into 1952, at which time the British decided to build a gas-cooled pile. Our earlier initiative was original to a much greater degree than we realized then.

The performance of an entirely novel device cannot be foreseen with any degree of accuracy. The project's authors ventured the hope that the power yield per ton of uranium would be somewhere between $\frac{1}{3}$ and $\frac{1}{2}$ Mw. This latter figure was considered as a ceiling; safety components, such as the concrete shell, were designed accordingly. The weight of uranium invested in the reactor was kept to its strict minimum of about 3 tons, corresponding to a total output between 1,000 and 1,500 kw.

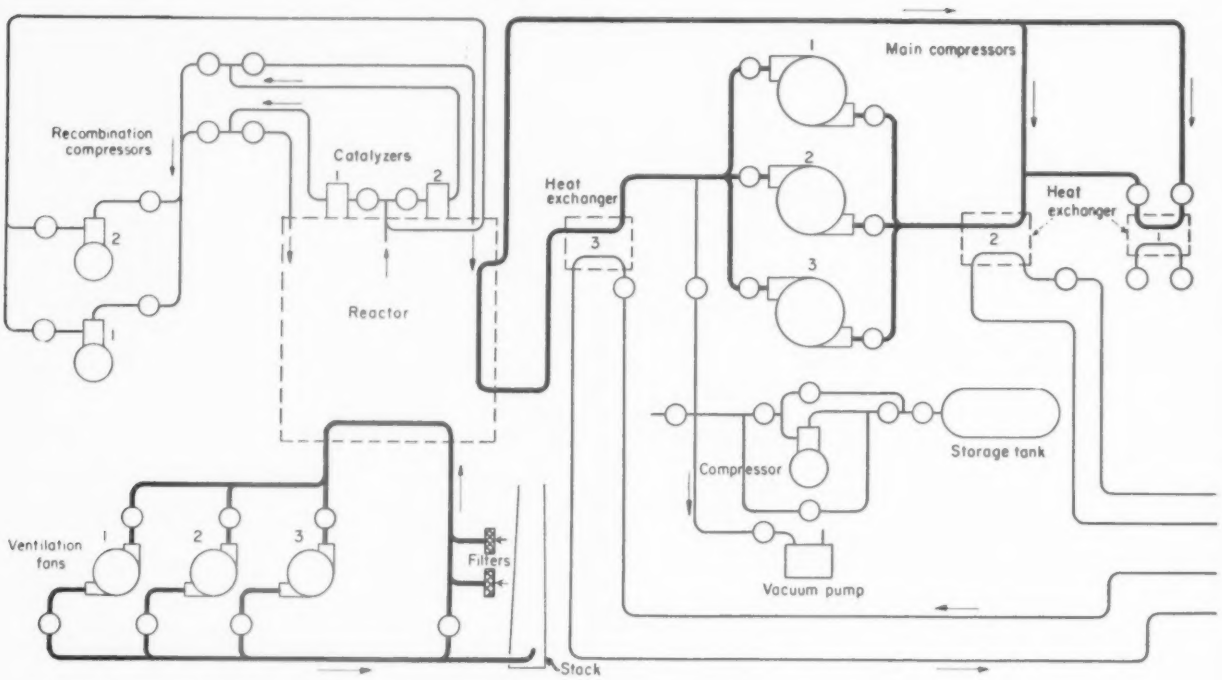
With its novel cooling system (see reactor description above), the Saclay reactor* was intended to open a new chapter of nuclear technology; its main purpose was to give useful information for designing bigger reactors free of whatever imperfections were found in the Saclay reactor itself. After having fulfilled its experimental role as regards the cooling system, the Saclay reactor could be assigned a permanent role as a source of radiations and radioisotopes.

* The reactor is so known at present. Neither the nickname "Cyrano," given in the Zeep-Bepo tradition, nor the Argonne-style symbol "P2" seem to have stuck.

Construction and Testing

After adoption of the project's main lines, a Commission headed by the High Commissioner was set up to control detailed design and construction. Its permanent executive body was the Project Office comprised of L. Kowarski as chairman responsible for the carrying out of the project; E. Le Meur, chief engineer; J. Stohr, special problems concerning the use of metals; and J. Yvon, calculations and theory. M. Surdin (electrical plant and electronics) joined the office at an early stage and a close contact was kept with

Five Piping Circuits Are Needed for Operation



1. PILE COOLING CIRCUIT (heavy lines) uses two blowers, with third as standby, drives gas towards reactor at maximum absolute pressure of 170 lb/in² for nitrogen. Each blower handles flow of 30–35 metric tons of gas per hour, uses 400 kw. Exchanger 3 cools gas to 20–30° C before entering reactor. Gas leaves reactor at about 70° C (higher temperatures will be possible shortly), gives up its heat to exchanger 2 (exchanger 1 not used at present), returns to blower, and is recycled through reactor.

2. WATER CIRCUIT (right) delivers cooling water to exchangers at about 15° C; temperature varies with atmospheric conditions. Heated water is pumped to top of cooling tower. Flow rate is about 200 metric tons/hr.

3. AUXILIARY GAS CIRCUIT (center) can be used to prime main circuit or to introduce additional gas. Storage gas tank is filled directly from delivery bottles; compressor raises gas pressure to main-circuit level. Vacuum pump removes gas from main circuit if change of gas is necessary.

4. RECOMBINATION CIRCUIT (top left) includes catalysis chamber to remove radiation-produced deuterium and oxygen gases from D_2O gas above heavy-water level in reactor tank. These gases are potential explosion hazard.

5. VENTILATION CIRCUIT (bottom left)

other participating divisions, especially with applied chemistry (under B. Goldschmidt) and physical chemistry (J. Gueron).

Chronologically, the work proceeded as follows:

1950: Detailed plans completed, main orders placed, building erected.

1951: Main mechanical and electrical components assembled, uranium rods manufactured and ready to be sheathed.

1952, first half: Assembly, sheathing of rods, completed.

At the project's earliest stages, our knowledge of metallic uranium and of its behavior under the influence of the relevant mechanical, chemical, and thermal factors, was very incomplete. An experimental inquiry into these topics was carried out parallel to reactor construction.

By the fall of 1951 our researches had shown clearly the necessity of inserting certain definite steps in the rod manufacturing process to insure their future satisfactory behavior. This meant that the set of rods nearly completed at that time would have to be replaced by another before the full design power could be reached.

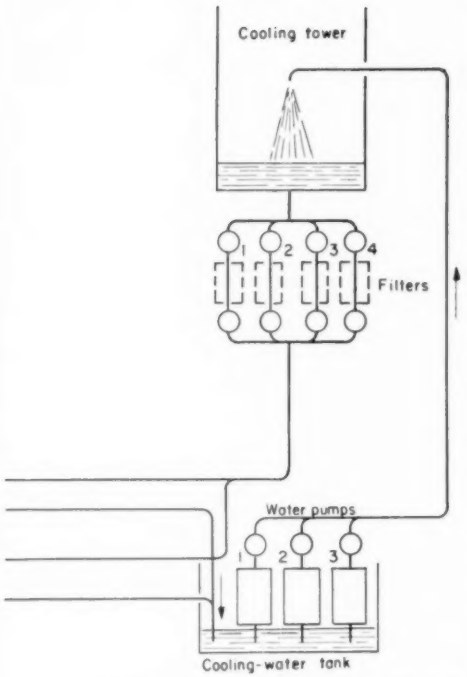
In the spring of 1952 the same provisional set of rods exhibited an unforeseen kind of corrosion; a quick study showed what preventive measures had to be taken in the future. The provisional set itself had to undergo a "curative" treatment that delayed its use by about 3 months.

Criticality was reached on October 27, 1952. After a few weeks' physical studies at a low power, the output was gradually raised in a series of tests completed in March, 1953. The main conclusions were:

1. Compressed-gas cooling in a closed circuit is basically satisfactory. There is no unforeseen radioactivation of the gas, by dust or otherwise. Blowers of an unusual (in French conditions) type work satisfactorily; the behavior of their gastight joints is good. Heat-transfer efficiency is rather better than expected.

2. In our 1949 ignorance of the behavior of the metallic uranium, we hoped that the surface temperature of our rods could reach 250° C at the hottest point. In the light of our increased metallurgical knowledge, however, we felt it advisable to go slow to avoid the risk of warping, which would endanger not only the functioning of the reactor but even the possibility of its repair. A surface maximum of 115° C was therefore imposed, pending replacement of provisional rods.

3. Gas-flow distribution between the 136 individual ducts, established at



removes air possibly contaminated with radioactivity from spaces adjoining coolant gas lines and reactor, exhausts it through stack. Supervised zone, in particular the graphite reflector, basement housing exchangers, hoods surrounding compressors, and trunk gas lines, is constantly monitored for atmospheric radioactivity. Recirculation of coolant gas may make impurities in it dangerously radioactive, and circuits are never 100% gastight.

first on theoretical grounds, had to be adjusted gradually in the light of our measurements on the spatial distribution of neutrons inside the reacting space. Suggestions as to the desirable machinery and accuracy of such adjustment have been derived for the benefit of our future installations.

4. The motion of the gas in the aluminum pipes lodged in the reacting space generates vibrations; this phenomenon was expected, but some of its manifestations, culminating in a succession of jerks and blows, were not. It was decided to insert in these internal pipes a set of metal pieces suitably shaped to attenuate the vibrations; and, on the other hand, to strengthen the joints between the "nuclear" (aluminum) and the "outer" (steel) region of the gas circuit.

After a period devoted to low-power physics, mechanical alterations and a detailed study (mechanical and metallurgical) of the second set of rods, full-power operation of the reactor was resumed in September, 1953, on an intermittent schedule, allowing for full-power runs, variable power, and shutdowns for inspection and adjustments. The limitation of rod temperature set a maximum for the full power, kept between 850 and 1,050 kw, that varied with the weather. Meteorological fluctuations have a direct effect on cooling efficiency of the water circuit.

All minor disturbances and stoppages during the subsequent half-year not only were easily remedied, but added to our understanding of this new kind of mechanism and prepared our engineering personnel for its much more arduous future task of running bigger and less approachable nuclear plants.

On the whole, our experience has shown that dismantling, repair, and reassembly operations seem to be less drastically precluded, even in the most active regions of the reactor (provided it is not operating), than we had expected. It seems that a similar conclusion, on a higher level of reactor technology, can be derived from the Canadian experience with the NRX accident.

In March, 1954, the provisional rods were taken out of the Saclay reactor; when insertion of the second set is completed, we expect much higher rod temperatures and (approximately) double the power output to be possible.* This stepwise rise towards design power and then beyond it, parallels the history of some earlier reactors. The British "Bepo" stayed a few years at about 60% of its design power until an essential forward step in metallurgy had been made. The necessary progress is in such cases usually due to observations made with the help of the reactor itself.

Results to Date

The contribution already brought by the Saclay reactor, at its 1,000-kw level, to French atomic development can be summarized under three headings:

1. As a "testing bench." Practical proof has been given for the first time that a reactor can be used, steadily and reliably, to heat a compressed-gas current, thus opening one way towards economic production of motive power. This way is, at present, being explored by the British.

In addition to this demonstration of feasibility, a number of smaller problems (interchange of gases, distribution of gas flow, vibrations, gastight joints) has been solved.

2. As an object of physical research. Numerous physical aspects of the chain reaction have been studied: spatial distribution of radiation in and around the reacting core; effect of different gases on the reactivity; kinetics of transient states; fission-product poisoning; propagation of neutron waves. Some of this work, notably by V. Raievski and J. Bernot, has been reported at the Oslo Conference of August, 1953, or published in the *Journal de Physique* (Paris).

3. As a source of radiations. At 1,000 kw, the Saclay reactor offered a higher central flux (about 4×10^{12}) than the British laboratory reactors and was comparable with Brookhaven. Its radiations were used for cross-section measurements, for study of neutron-induced displacement in crystalline lattices ("Wigner effect"), and for occasional radioisotope production. The Saclay reactor is not much of a plutonium producer. This production is proportional to the total uranium mass present in the reactor, whereas the designers aimed precisely at keeping this mass as low as possible. A few dozen grams already accumulated will serve, however, to increase our knowledge of this element.

Future Prospects

France's present atomic "Five-Year Plan" aims at enlarging the industrial scope of the national atomic effort and at bringing France to the threshold of a paying power production. Reactor development is directed simultaneously at the production of plutonium in "cold," Windscale-like structures, and the building of high-temperature and high-flux prototypes.

The Saclay reactor, even after having transcended its "provisional" stage is, then, soon to lose its prominent position in the vanguard of French atomic progress. The gropings of its adolescence having yielded their expected harvest of knowledge, the reactor will soon reach its quiet maturity, as a steady source of radiations and radioisotopes. END

* NOTE ADDED IN PROOF: This operation, ably directed by J. Robert and R. Uguen, was completed in June. Early in July, steady operation was resumed at 1,500 kw with the hot point provisionally at 200° C. Higher temperatures and outputs will be attempted shortly.

How Important Is Surface Contamination?

A survey of radium and uranium plants shows that surface monitoring is less indicative of personnel hazard than air sampling and bioassay. Costly surface decontamination is unnecessary unless warranted by effects on airborne dust or external radiation

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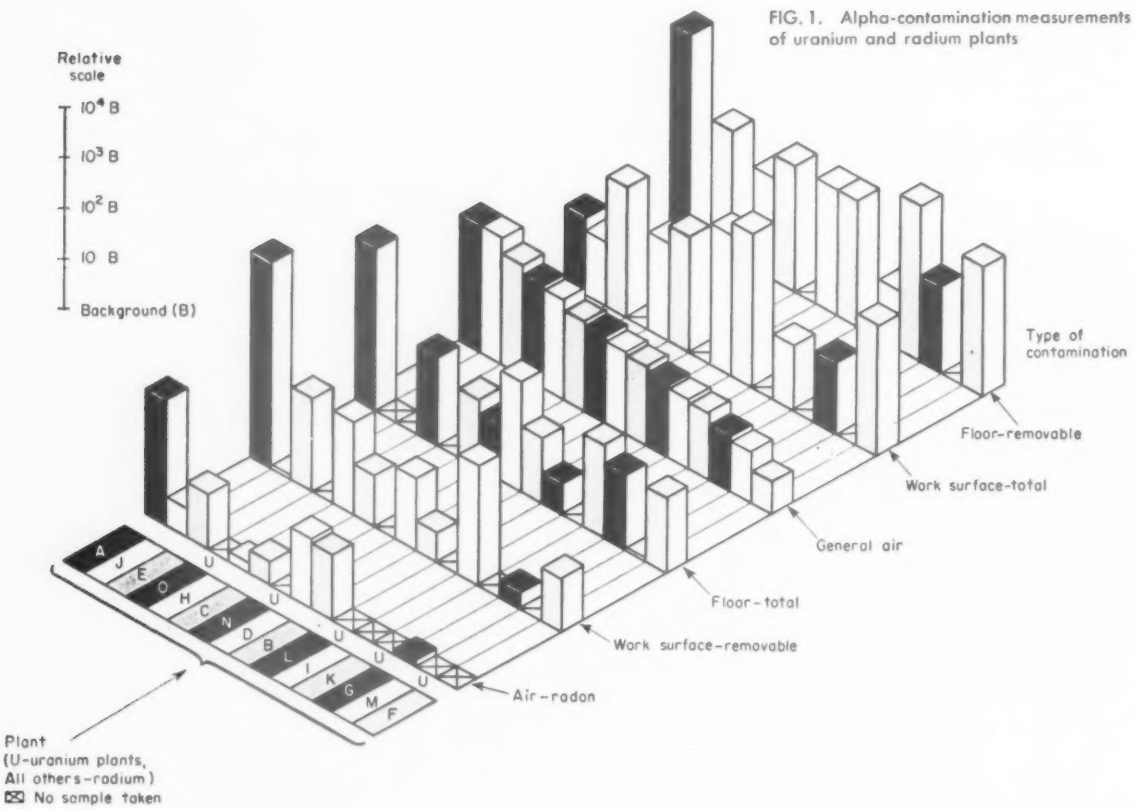

FIG. 1. Alpha-contamination measurements of uranium and radium plants

THE COST OF DECONTAMINATING and sometimes replacing surfaces regarded as excessively contaminated with radioactivity is often a burden on the maintenance program of plants and laboratories using radioactive materials. In this problem of surface contamination, quantitative information has not been as available as in the case of radioactive contamination of air and water.

In some laboratories, careful surveys of surface contamination are necessary to maintain a low radiation background for counting purposes. However, our discussion is concerned with the more usual situation in which surface contamination is considered in relation to the risk of ingestion or inhalation.

We have undertaken studies of surface contamination in radium dial plants, radium processing plants, and uranium refineries in an effort to obtain at least semiquantitative information about the relationship between surface contamination and atmospheric dustiness and also various indices of absorption, such as urinary excretion and breath radon analysis.

Radium Plants

The radium industry was limited to the preparation of materials on a relatively small scale for medical and research applications until the onset of World War I, during which great impetus resulted from the development of self-luminous dials for watches and instruments. In 1924 and 1925 (*3*, *4*), a number of radium poisoning cases attracted attention to the potential hazards of the industry. These cases of radium poisoning are attributed to the practice of mouth pointing the brushes used to apply paint to dials. This practice has long been discontinued and, with the adoption by the industry of sensible industrial hygiene

TABLE 1—Summary of Plant Measurements

	Floor contamination (dpm/100 cm²) × 10⁻³				*Work Surface contamination (dpm/100 cm²) × 10⁻³*			
Plant	*Total*	*Removable**	*General Air contamination† (dpm/m³)*	*Room radon (μμc/l)*	*Total*	*Removable**	*Breath radon (μμc/l)*	
A	5,000	70,000	540	800	3,000	2,500,000	7.5	H‡
	1,900	21,000	320	340	1,059	1,200,000	3.0	M
	80	2,000	160	60	13	750	0.4	L
	7	8	34	6	14	22	3	No.
B	32	739	51	16	5,000	51,200	1.5	H
	16	315	29	16	1,290	238	0.8	M
	6	148	8	16	24	55	0.3	L
	4	5	2	2	4	9	5	No.
C	47	730	190	2	500	1,400		H
	21	365	50	2	188	722		M
	8	120	10	2	8	14		L
	4	4	5	2	8	8		No.
D	300	610	68	36	1,000	13,000		H
	144	405	36	18	650	1,991		M
	1	200	16	1	350	32		L
	4	4	5	2	2	20		No.
E		607	485	12	2,600	54,700	3.2	H
		349	186	9	428	6,900	1.1	M
		154	28	6	2	155	0.2	L
		6	7	6	19	33	10	No.
F	80	470	4		2,400	4,700		H
	23	412	3		177	824		M
	6	120	2		2	2		L
	39	5	3		59	10		No.
G		50		1	80	863	0.1	H
	24	47	10	1	21	123	0.1	M
		43		1	0	1	0.1	L
	1	2	1	2	10	16	3	No.
H		155	260	1	190	635	0.8	H
		104	78	1	75	161	0.4	M
		53	10	1	19	4	0.2	L
		2	4	2	6	12	3	No.
I			30		40	85,500	0.4	H
		13	20		15	23,600	0.3	M
			0		0	1,400	0.2	L
		1	3		11	13	2	No.
J			350	3	450	910		H
			326	2.5	16	15		M
			261	2	2	2		L
				2				No.
K	80	4,500	40					H
	65	1,530	19					M
	50	250	5					L
	2	15	16					No.
L	12		72					H
	2		23					M
	0.2		8					L
	112		8					No.
M	1.6		13					H
	0.6		8					M
	0.2		3					L
N	23		127					H
	10		44					M
	1		13					L
O	64		313					H
	50		97					M
	10		21					L

* Figures for removable contamination obtained from smears of about 100 cm².

† The sampling times employed for air contamination were, in general, from 20 to 30 min.

‡ The notations in the last column refer to highest value (H), mean value (M), lowest value (L) and number of samples (No.).

* PRESENT ADDRESS: National Lead Co. of Ohio.

practices, the radium-dial painting industry has enjoyed a good health record in recent years.

Seven radium dial-painting establishments were included in our study. In addition, we surveyed two plants that perform chemical manufacturing operations on radium salts. The surveys included alpha-meter readings and smear samples (*5*) at random locations on work surfaces, as well as selective readings and smears from tools, instruments, and smocks. Air dust samples were collected in the breathing zone of workers as well as in the general air in workrooms. The surveys were scheduled so that expired air samples could be collected from employees on a Monday morning before entering the workrooms. Where possible, these samples were taken after a long (3-day) weekend or after a vacation period, using a technique devised by Harley *et al.* (*6*).

One plant was surveyed three times for reasons given later. All but the two large plants were dial-painting establishments. A total of 26 employees of six of the plants were sampled (in duplicate) for breath radon.

A summary of the measurements is given in Table 1 and Fig. 1.

Uranium Plants

Data from five uranium-processing plants operating under contract with the Atomic Energy Commission have been reviewed. These plants are engaged in the preparation of various uranium compounds, including the metal.

In these plants, the level of uranium dust contamination of the workroom air is the criterion by which the existence of an internal radiation risk is judged. Local exhaust ventilation is the principal method by which air dustiness is reduced. The plant housekeeping procedures are, of course, an important part of the radiological hygiene program, but these are typical of modern-day chemical plant maintenance. No routine measurements of surface contamination are made. For comparison purposes, however, surface contamination was measured and sampled in five of these plants, and the results are shown in Table 2.

Discussion of Data

In Fig. 1, the collected data were arranged with respect to the degree of general air (dust) contamination, since there is more evidence to support this parameter than the other alpha contamination measurements as a criterion of the general plant radiological hygiene. An examination of the figure shows slight relationships between certain other parameters. For example, the "floor-removable," "floor-total" and "work surface-removable" contamination show some trend in the same direction as the "general-air" contamination. Omission of Plant A data in most cases would reduce, or eliminate, the trend. Elimination of this plant could possibly be justified because of the difference in its general methods of operation from all the other plants. It is the only plant engaged exclusively in chemical separation and has been located in the same building for many years with little, if any, change in equipment or methods.

To inquire as to whether floor contamination is related to the dustiness of the workroom air, the mean value of general air contamination was plotted against the value of total floor contamination (Fig. 2). This scatter diagram suggests that a slight relationship exists. An eye-fitted curve indicates that if a limit were to be set for alpha floor contamination because of its relationship to airborne dust in these plants, it should be of the order of 10^5 dpm/100 cm² instead of the values of from 500 to 2,000 currently used. This relation is in very good agreement with the values arrived at under simulated working conditions by Bailey and Rohr (*7*). They give a ratio of

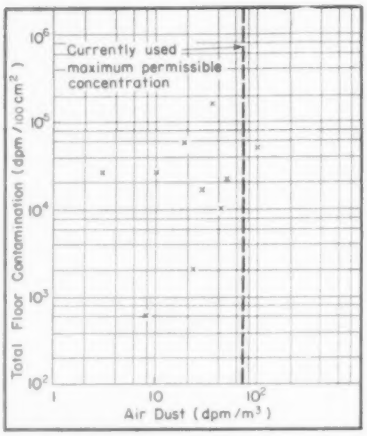

FIG. 2. Total floor contamination (fixed and transferable) monitored with meter

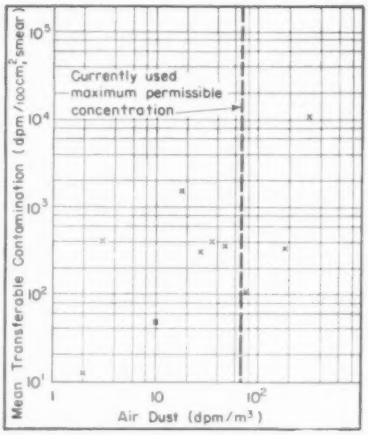

FIG. 3. Mean transferable contamination (dpm/100 cm² smear)

TABLE 2—U-Plant Surface Activity

Plant		Smear (dpm/100 cm²)	Meter (dpm/100 cm²)	Airborne (dpm/m³)
J	H	45,000	800,000	40
	M	15,000	600,000	19
	L	2,500	500,000	5
L	H		11,700	72.4
	M		2,000	22.5
	L		200	8.3
M	H		1,600	12.7
	M		600	8.1
	L		200	3.0
N	H		22,900	127
	M		9,900	43.7
	L		1,100	12.8
O	H		64,000	313
	M		50,000	97.1
	L		10,000	20.5

TABLE 3—U-Plant Excretion Samples

Plant		General air (dpm/m³)	Urinary uranium (mg/liter)
L	H	77	0.025
	M	30	0.011
	L	6	0.001
	No.	35	35
N	H		0.022
	M	82	0.0082
	L		0.003
	No.		19
P	H	564	0.058
	M	234	0.021
	L	72	0.005
	No.	50	50

20 (dpm/m^3 air)/(dpm/cm^2 surface), which compares to our ratio (converted to the same units) of 7 under actual working conditions.

It was expected that there should be a closer relationship between removable floor contamination and the dustiness of the general workroom atmosphere. Although a lesser relationship appears to exist between these variables (Fig. 3), an eye-fitted curve would indicate a removable contamination figure of the order of 10^3 dpm/100 cm^2 to correspond to the maximum permissible air dust concentrations used by us for uranium and radium.

The urinary excretion of uranium, as given in Table 3, is not of a hazardous order. The levels are well below the value of 50 μg per 24 hr recommended as the upper level of the permissible range by Newman (*8*). These levels can be explained by the exposure to inhaled uranium dust. It will be noted that the employees in plant N (high surface contamination but low airborne dust) have a low excretion rate compared with employees in the other uranium plants.

Of the 26 individuals whose breaths were sampled for radon, five exhaled concentrations in excess of the recommended maximum of 10^{-12} curies per liter. The five cases were studied with the following conclusions:

1. One case (in Plant A) can be attributed to generally poor industrial hygiene, of which the high levels of surface contamination and air dustiness are symptoms. This plant is engaged in many operations affording an opportunity for heavy-breathing-zone contamination, which was not sampled in this survey.

2. One case involved a worker engaged in a particularly hazardous operation (dial stripping), which is known to generate relatively large amounts of dust (Plant B).

3. Three cases involved workers who had been engaged in this work in excess of eight years, partly in another plant under conditions reported to have offered greater potential exposure than at the plant surveyed (Plant E).

It should be pointed out that the 26 individuals selected for breath sampling were chosen because of their relatively heavy exposure, either because of the work performed or their length of service. They comprised only about 10% of the total exposed employees of all the plants surveyed.

In one plant, an opportunity was afforded to study the effect of time on the levels of surface contamination. This plant was surveyed after many years of operation prior to moving to a new location where another survey was made three weeks after the operations had been transferred and new benches and hoods had been installed. The survey was repeated after another six months. The results of the three surveys are shown as D, B and C, respectively, in Table 1. It is interesting that the order of magnitude of the total and removable surface contamination in this plant, as well as the air dust and room radon, was about the same for all three surveys. Actually, the final survey showed a decrease from the earlier survey of the new plant on all counts.

Conclusions

The data suggest that contamination of surfaces by radioactive materials is not in itself a good criterion for judging whether hazardous conditions exist in a work area. It is probably unsound to establish a maximum permissible level of surface contamination, because the acceptable level in any given situation will depend on many factors, such as the physical state of the contamination, the amount of traffic in the area, and ventilation.

In view of the high relative radiotoxicity of radium and the satisfactory health record of this industry in recent years, the levels of surface contamination prevailing in the plants studied can be regarded as not objectionable. Time-consuming surface monitoring procedures should be deemphasized in relation to air sampling and bioassay criteria of absorption. Costly decontamination of surfaces need not be undertaken unless the surfaces are so heavily contaminated as to be reflected in excessive atmospheric dustiness or external radiation levels.

* * *

This study was possible only because of the splendid cooperation of many others. Several non-AEC plants made their facilities available to us, for which we express our appreciation.

Several surveys were made in cooperation with the New York State Department of Labor, Division of Industrial Hygiene and Safety Standards. Saul Harris, radiophysicist of the division, arranged for the surveys and assisted in them.

The breath-radon samples were measured by the Analytical Branch of this laboratory and some of the sampling was done personally by Dr. John Harley, Chief. Keran O'Brien of the Radiation Branch assisted in assembling much of the data.

Much of the urinary uranium data and measurements showing their relationship to air-dust concentrations were obtained through the cooperation of Mont Mason of the Mallinckrodt Chemical Company.

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Is Ingestion Important?

Uncertainty as to the significance of surface contamination in the estimation of personnel hazard is evident in the various standards adopted at major atomic energy installations. Maximum levels of permissible alpha surface contamination range from 500 to 2,000 cpm/100 cm^2, as measured with a survey meter, and from zero to 100 cpm for smears obtained by wiping a piece of filter paper over an area of the order of 100 cm^2.

Until about 25 years ago, it was believed that ingestion was a major factor in industrial intoxication. This was partly due to the experience in the radium dial-painting industry. In the second quarter of this century, inhalation rather than ingestion came to be regarded as the principal mechanism by which a toxic substance is absorbed into the body (1, 2).

In excluding ingestion as an important factor, there is no intention to underestimate the dangers of unusual circumstances that might result in the ingestion of excessive amounts of a toxic or radioactive substance. However, under ordinary conditions of workroom or laboratory operation, there is insignificant opportunity for tactile transport of contaminants to the mouth.

REPRESENTATIVE TUBERS from control and irradiated samples 8 months after irradiation. Same tubers are shown on front cover 15 months after irradiation

Improved Storage Quality of Potato Tubers after Exposure to Co^{60} Gammas

Gamma radiation, particularly from 5,000 to 20,000 r, can greatly prolong storage life of potatoes. Katahdin variety tubers were exposed to about 1,250, 5,000, 10,000, 20,000, 80,000, and 106,250 r; effects on taste, sprouting, shrinkage, internal black spotting and texture were followed for 18 months. A taste panel preferred irradiated samples over controls after 8 months and found no undesirable taste in any irradiated samples even after 18 months' storage. Sprouting was reduced at the two lower dosages, completely inhibited at 20,000 r or higher. Weight loss during storage was greatly reduced at all but lowest dosage. After prolonged storage, lowest dosage sample and controls showed severe softening; highest doses produced some softening. Potatoes irradiated with 20,000 r were still firm and excellent in appearance after 18 months of storage

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REACTIONS OF POTATO TUBERS and growing potato plants to various dosages and kinds of ionizing radiation have been under observation for several years at Brookhaven National Laboratory (*1–5*). Several of these experiments indicated that the storage quality of irradiated potatoes might be considerably better than those of untreated tubers. A specific experiment was undertaken in December, 1952, to test the validity of these observations; results are reported here.

Tubers of the Katahdin variety weighing between 90 and 125 gm each were selected for irradiation. The somewhat small size of the potatoes was necessitated by the limited inside diameter of the hollow radiation source used. The tubers were exposed at the Brookhaven hot laboratory with gamma radiation from Co^{60}. The facilities used for this experiment, which have been described elsewhere (*6*), gave a dose rate of 17,500 r/hr. Four lots of 24 tubers received total dosages of 1,250, 5,000, 20,000 and 80,000 r respectively. A fifth lot of only 5 tubers received approximately 106,250 r. This lot was used for tasting and photography only. After irradiation the potatoes were placed in 1-gal cardboard ice cream containers and kept in a vegetable storage room (temperature varied from about 2° to 10° C) for 1 month, after which they were moved to a constant-temperature cold room held at 5° to 7° C.

Physical Observations

Following the irradiations, observations and measurements were made for a period of 18 months. Representative tubers from each sample, photographed after 8 months, are shown above. This same set of tubers photographed after 15 months of storage is shown on the front cover. As clearly indicated above and on the cover, a definite inhibition of sprouting occurs after 1,250 r, and almost complete inhibition after doses of 5,000 r or higher. It should be noted that the 5,000-r tuber on the cover is more wrinkled and has considerably more sprouts than the average for this dosage.

After 8 months of storage, the sprouts from the control and two lower dosages were removed and weighed. Sprouting at the higher dosages was negligible. The mean weights of the tubers and of the sprouts in the control and irradiated samples are presented in Table 1. The percentage loss in weight after 8 months storage was 9.7% in the controls, 10.8% in the 80,000-r lot, and a minimum loss of only 7.3% in the 20,000-r lot. Between 8 and 18 months a new set of sprouts developed on the control and low-dosage samples; values in the sixth column of Table 1 represent the combined sprout weights of both weighings. After 18 months of storage the weight loss had reached 55% in the controls but considerably less in all the irradiated samples, with the minimum loss of only 20% in the 20,000-r lot.

The results presented in Table 1 clearly show that the irradiated samples had fewer sprouts and suffered less loss in weight than the controls. However, since the differences in loss of weight in the irradiated samples re-

TABLE 1—Effect of Gamma Radiation on Sprouting and Loss of Weight in Potato Tubers 8 and 18 Months after Irradiation

	At 8 months			*At 18 months*		
Dosage	*Mean tuber weight (gm)*†	*Mean sprout wt. per tuber (gm)*	*Loss in weight (%)*§	*Mean tuber weight (gm)*†	*Mean sprout wt. per tuber (gm)*‡	*Loss in weight (%)*§
Control	96.3	5.4	9.7	60.7	19.3	55.5
1,250	98.9	0.7	9.5	70.8	10.9	42.9
5,000	94.3	*	9.1	79.7	1.3	24.7
20,000	95.8	*	7.3	84.7	*	20.3
80,000	95.6	*	10.8	75.5	*	26.9
106,250	89.3	*	—	—	*	—

* Negligible sprouting at this dosage.
† Tuber weight includes sprouts.
‡ These values include weight of sprouts removed after 8 months.
§ Loss in weight includes sprouting, i.e., actual weight loss plus weight of sprouts.

ceiving 5,000 r, 20,000 r and 80,000 r are not significantly different, other criteria must be called upon to help to decide the optimum dosage. These other criteria are appearance, texture, taste and nutritional value.

The external appearance of the irradiated tubers after 8 months storage differed little from each other or from the controls, except in regard to sprouting (Fig. 1). However, after 18 months, the 20,000-r lot appeared to be in much better condition than the controls or the 1,250-r or 5,000-r lots (cover picture). The visible difference between the three higher dosages was less obvious. On the basis of appearance alone it is, therefore, difficult to choose one of these three dosages as being clearly superior to the other two.

Taste Tests, Other Factors

The results of taste tests after 1, 4, 8 and 18 months storage are given in Table 2. At each test one or two tubers from each sample were selected and cooked in salted water. Treatments were unknown to the tasters.

Up to 4 months of storage, the tests failed to show any significant difference in taste between control and irradiated tubers or between the different irradiated samples. However, by the end of 8 months of storage, the tasters showed a definite preference for the irradiated samples, and again no clear difference between the different dosages. After 18 months only three samples appeared to be in good enough condition to warrant taste testing. All three samples (5,000, 20,000 and 80,000 r) were found acceptable by most of the taste panel. However, five of the nine tasters noted that the 80,000-r sample had a sweet taste. It seems, therefore, that on the basis of taste the 5,000- or 20,000-r samples were the most satisfactory after 18 months.

Texture is also an important quality in potatoes. Up to 4 months after irradiation the potatoes in all the samples were firm and unwrinkled. At 8 months the 5,000- and 20,000-r samples were still in good condition, but the others showed some tendency to soften. At 18 months the 5,000- and 20,000-r samples were mostly still quite firm, the 80,000- and 106,250-r samples were somewhat softer, while the control and 1,250-r samples were very soft and badly wrinkled.

Considering the results after 8 and 18 months storage, we can try to select the best dosage or dosage range. The 42.9% loss due to sprouting and shrinkage would make the low dosage (1,250 r) less desirable than 5,000 or 20,000 r, which lost only 24.7 and 20.3% respectively. Likewise 80,000 r seems to offer no advantage and can be eliminated on the basis of requiring an unduly long exposure time. The same can be assumed for higher dosages.

Certain other factors should be taken into account in choosing a suitable irradiation dosage. It is known that potatoes have a tendency to develop black spotting following exposure to ionizing radiation (*5, 7, 8*). This darkening is not visible externally except at very high dosages (*5*) but is nevertheless not desirable. The nutritional value of the potatoes was not tested, but it seems possible that the vitamin content might be reduced at high dosages as has been reported for orange juice (*9*). These considerations, plus those already mentioned, argue in favor of keeping dose as small as possible.

It is concluded that sprouting of potatoes can be greatly reduced at 5,000 r and completely inhibited at 20,000 r, and that these dosages prolong the useful storage life of the tubers. The storage temperature was 5° to 7° C during most of the storage period, but storage at room temperature with dosages as low as 10,000 r also seems to give good control of sprouting and associated changes (*10*). Further work at a number of dosages between 1,250 and 40,000 r is being conducted in collaboration with Dr. R. Sawyer of the Long Island Vegetable Research Farm at Riverhead, New York. These results will be published in detail elsewhere.

* * *

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TABLE 2—Results of Taste Tests on Control and Irradiated Tubers

Time after irradiation (months)	*No. of tasters*	*No. of tasters who found taste acceptable*					
		Control	*1,250*	*5,000*	*20,000*	*80,000*	*106,250*
1	9	6	8	7	6	7	—
4	9	8	8	9	8	8	—
8	11	4	10	7	10	7	7
18	9	—	—	7	8	8	—

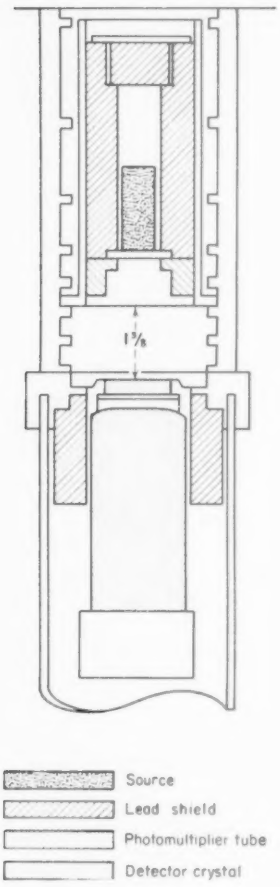

FIG. 1. Gamma scintillation photometer source-detector arrangement

Gamma Absorptiometry:

A New Tool for Analytical Chemistry

Gamma scintillation photometry offers several advantages over X-ray photometry:

- **Extreme stability of source intensity**
- **Decreased instrument complexity, size, and cost**
- **More nearly monoenergetic emission**
- **Much wider range of photon energies (20–2,000 kev)**

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General Electric Company, Richland, Washington

THE ABSORPTIOMETRIC TECHNIQUE employing radioisotopes as a source of gamma photons or X-radiation could be applied to a variety of analytical problems, e.g., continuous chemical analysis for process control. In many applications, such as high-mass, high-atomic-number samples, radioisotopes emitting photons in the range 50–400 kev compete with customary X-ray photometer sources and may also permit, at reasonable cost, the application of this technique to determinations not feasible using X-ray tubes.

Gamma Absorptiometry

The principal advantages of using radioisotopes as gamma photon sources are the following:

1. Extreme stability of source intensity.
2. Decreased instrument complexity.
3. Compact size.
4. More nearly monoenergetic characteristic of the emitted photons.
5. Much wider range of photon energies available, about 20–2,000 kev.
6. Lower over-all cost of the instrument.

The principal limitation is the low intensity generally available compared to the extremely high intensities from X-ray tubes. Because of this, these sources cannot effectively compete with X-ray photometry in the energy range up to 50 kev. In the range 50–400 kev, however, these sources offer attractive possibilities.

Adequate shielding to safe radiation levels is easily accomplished. A 1-in.-thick lead shield was sufficient to reduce the radiation level from the sources used in the present study to less than 10 mr/hr.

Gamma-Photon Detectors

A relatively low gamma source intensity is desirable to reduce the radiation hazard, or may be additionally imposed because of low specific activity of the source. To compensate for the low intensities available, efficient gamma-photon detectors must be used. Another consideration in choosing a detector is its relative efficiency to each of several photons that may be emitted from a single radioisotope. If chosen

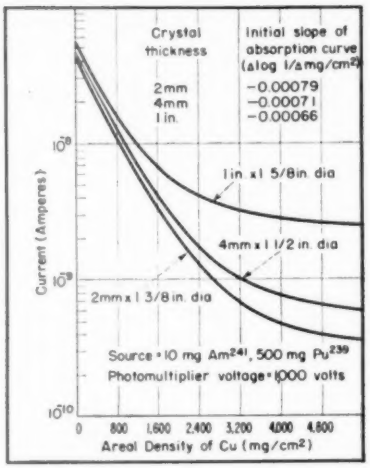

Crystal thickness
Initial slope of absorption curve (Δlog I/Δmg/cm²)
2mm −0.00079
4mm −0.00071
1 in. −0.00066
1 in. x 1 5/8 in. dia
4mm x 1 1/2 in. dia
2mm x 1 3/8 in. dia
Source = 10 mg Am²⁴¹, 500 mg Pu²³⁹
Photomultiplier voltage = 1,000 volts
Current (Amperes)
Areal Density of Cu (mg/cm²)

FIG. 2. Gamma-absorption curves for Cu as function of NaI(Tl) crystal thickness

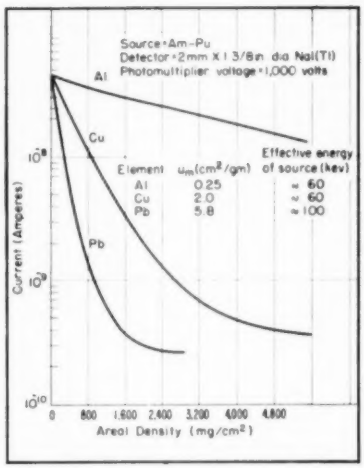
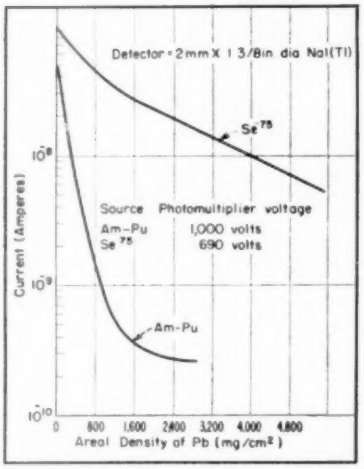


FIG. 3. Gamma-absorption curves as function of absorber atomic mass



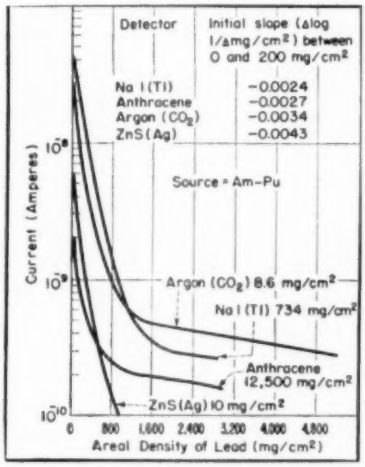


FIG. 4. Gamma-absorption curves for Pb (left) as function of source energy and (right) using various detectors

to be efficient only for the lowest energy component, the absorption measurements obtained can be made to correspond initially to a nearly monoenergetic, low-energy source.

A wide variety of gamma-photon detectors are available (*1*). Each type has characteristics peculiarly advantageous in a given absorptiometric method. Ionization chambers and gas-filled proportional counters, by utilizing various gases and gas pressures, are useful in obtaining optimum detection efficiency at energies below 100 kev. The organic and inorganic scintillation phosphors coupled with stable photomultiplier tubes are applicable for a wide range of gamma energies and are especially desirable for higher-energy photons (*2*). An optimum energy vs detection efficiency relationship can be selected by properly choosing the mass presented to the radiation by the phosphor.

Both pulse-counting and current-measuring techniques can be used in determining the total gamma flux incident on the detector. Given sufficient gamma intensity at the detector, the current measurement technique is the more direct, rapid, and accurate method and will find broader application. However, where pulse-amplitude discrimination is desired, pulse counting will be useful.

In the application of gamma-photon sources emitting a number of low-energy components (<100 kev), differential pulse-amplitude discrimination permits very nearly monoenergetic interpretation of the polyenergetic gamma-photon absorption with some sacrifice in measured intensity.

As in X-ray photometry, the response of the gamma detector may be a critical function of the applied voltage. Again, the effect of this critical dependence can be eliminated by rapid commutation of the gamma source between sample and standard. However, by employing stabilized high-voltage supplies, fluctuations in current due to fluctuations in the detector voltage can be essentially eliminated. Voltage supplies providing fluctuations of only $\pm 0.002\%/10\%$ change in line voltage are readily available.

Absorption Measurements

A series of gamma-absorption measurements were made employing the source-detector arrangement of Fig. 1 with a Beckman Model V micromicroammeter and an Offner Type 961A negative high-voltage supply. The gamma source was an americium-plutonium mixture (10 mg Am^{241}, 500 mg Pu^{239}). Approximately 10 gm of inactive, metallic oxides were also present in this source mixture; source self-absorption was therefore appreciable for the lower-energy photons emitted by Am and Pu.

Figure 2 shows the copper absorption curves obtained with scintillation crystals of three different thicknesses as the detectors. Since the sensitivity of any method based on gamma absorption will increase as the initial slope of the absorption curve becomes more negative, the desirability of very thin NaI(Tl) crystals is evident in the application of the Am-Pu source. The absorption of the gamma energies associated with this source as a function of the atomic mass of the absorbing material is shown in Fig. 3. In each of the absorption curves reported here, no correction is made for the background contribution to the measured current. Because of the large signal-to-background ratios, this correction is not significant in determining the initial slopes of the absorption curves.

The slope of the absorption curve is a function of the gamma photon energies of the source. As an example, the lead absorption curves for the Am-Pu source and a Se^{75} source are compared in Fig. 4 (see also Table 1). The greater intensity of the Se^{75} source necessitated

the use of a lower voltage on the photomultiplier to obtain currents of the same order of magnitude as those produced in this detector by the Am-Pu source.

As has been noted earlier, X-ray or γ-ray absorption can distinguish between elements of different atomic number. The ability to distinguish is a function of the photon energy and is indicated by the ratio of the mass absorption coefficients for the two elements to be compared. However, the effective discrimination between elements of different atomic number is greater, as observed in the present study, than would be predicted by calculations based on mass absorption coefficients given in the literature. Table 2 shows the relative effectiveness of lead and aluminum as absorbers for the gamma-photon energies emitted by three different sources. Included in Table 2 is the Al/Pb absorption ratio for a 30-kev X-ray measured using a General Electric X-ray photometer (*3*) equipped with a D-3 head. Also included in Table 2 are the Al/Pb absorption ratios that would be predicted from the ratio of the mass absorption coefficients for Al and Pb at the most abundant photon energies involved.

To show how the gamma photometer compares as an analytical tool to the X-ray photometer, the Al/Pb absorption ratios shown in Table 2 were determined with one half-thickness of lead in the photometer beam at all times. A lead absorber increment (Δ Pb) was then added and the current decrease noted. The increment of lead absorber was then replaced with aluminum absorber (Δ Al) until the same decrease in current was obtained. This method for the determination of the Al/Pb absorption ratio permits a valid estimate of the ability to discriminate against aluminum when lead concentration is being measured.

More favorable (larger) Al/Pb ratios may be obtained by comparing the experimentally determined mass absorption coefficients (see Fig. 3). This is thought to be caused by the half-thickness of lead present during the determination of the Al/Pb ratios of Table 2, which increased the effective energy of the polyenergetic sources used. In addition, the absorber increments were placed between the source and the half-thickness of lead. Placing these increments between the lead half-thickness and the detector results in a greater current reduction and a correspondingly improved Al/Pb ratio. This is

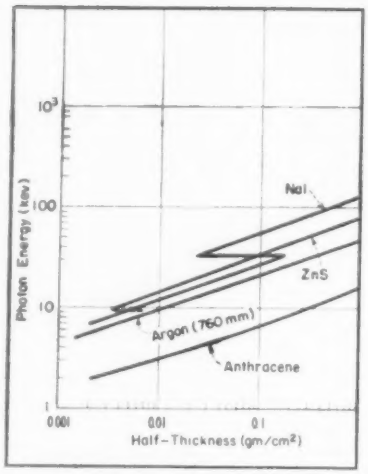


FIG. 5. Half-thickness vs photon energy

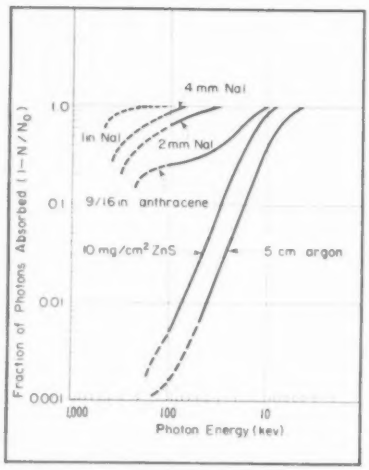


FIG. 6. Fractional absorption for various detectors

TABLE 1—Source Photon Emissions

Isotope	*Photon energy (kev)*	*Abundance (%)*
Am^{241}	60	43
	17	28
	14	18
	21	7.5
	26	3.2
Pu^{239}	53	Total
	100	less than
	124	0.1%
	39	
	384	
Se^{75}	269	57
	138	15
	77	11
	405	11
	281	4
	124	2

TABLE 2—Ratio of Equivalent Absorber Thicknesses (Al/Pb) Using 2-mm NaI (Tl) Detector

Source	*Predominate photon energy (kev)*	*Pb ½ th. (mg/cm²)*	*Δ Pb (mg/cm²)*	*Equiv. Δ Al (mg/cm²)*	*Observed ratio Al/Pb*	*Predicted ratio Al/Pb* (4)
Cr^{51}	320	2,125	281	1,567	5.6	3.57
Se^{75}	260	660	62	722	11.6	4.64
Am^{241}	60	125	12.2	217	17.8	13.2
30-kev X-ray	30		5.89	141	24	21.8
						27.2 (*5*)

TABLE 3—Am-Pu Source-to-Background Ratio for Various Detectors

Detector and areal density (mg/cm²)	*Initial slope of Pb curve*	*Detector voltage (volts)*	I_0 *(amperes)*	I_{Bkg} *(amperes)*	I_0/I_{Bkg}
ZnS(AG), 10	−0.0043	1,000	1.1×10^{-9}	1×10^{-11}	100
NaI(Tl), 734	−0.0024	1,000	4.5×10^{-8}	5×10^{-11}	900
Argon(CO_2), 8.6	−0.0034	2,400	3.3×10^{-8}	6×10^{-11}	550
Anthracene, 1,790	−0.0027	1,000	2.4×10^{-9}	6×10^{-11}	40
NaI(Tl), 1,468		1,000	4.6×10^{-8}	1×10^{-10}	460
NaI(Tl), 9,322		1,000	5.7×10^{-8}	2×10^{-10}	280

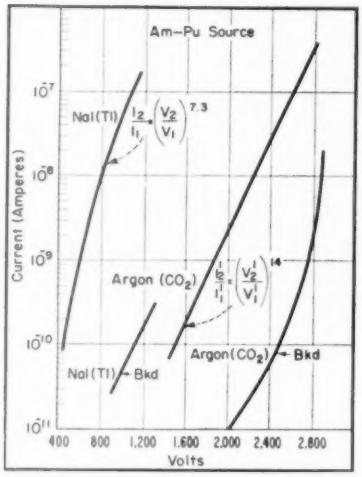


FIG. 7. Voltage vs current for NaI(Tl) and Argon detectors

X-RAY ABSORPTIOMETRY

X-ray absorptiometry (3, 6–15) provides a simple, rapid, accurate, and precise method for nondestructive analysis of a wide variety of materials. It is particularly suited to the determination of an element having an atomic mass that is high compared to the atomic masses of any other elements present in admixture. The most unique advantage of X-ray absorptiometry over other photometric methods is the independence of X-ray absorption on the physical state of the absorbing material.

Problems in applying X-ray absorption to chemical analysis are: (1) critical dependence of X-ray intensity on source input voltage (intensity of soft X-rays may vary as 24th power of tube voltage); (2) possible dependence of detector sensitivity on voltage (photomultiplier current varies approximately as 7th power of anode voltage); (3) limited range of X-ray energies readily available (approximately 1–50 kev); (4) uncertainties introduced in assigning absorption coefficients because of polyenergetic characteristic of X-rays.

The first two problems have been virtually eliminated by a repetitive, null-balance method for comparing the absorption of a sample to that of a known standard; this necessarily increases over-all cost and complexity. Lambert (14) reports a precision for a single determination of ±0.25% at the 99% confidence level, based on 98 determinations in the analysis of 40-gm/l uranium solutions. This instrument also permits excellent discrimination among elements of different atomic number.

The third limitation is offset to a considerable degree by the extremely high X-ray intensities available using X-ray tubes, e.g., 10^{18} photons/min.

attributed to the absorption of low-energy, characteristic X-rays excited in the lead.

In passing, a situation was encountered during the course of this work that, although straightforward, has not been discussed with respect to γ-ray absorption. With the Se^{75} source and a 2-mm NaI(Tl) crystal as the detector (poor response for high photon energies), an increase in current is observed when a thin absorber is placed between the source and detector. This is attributed to the fact that the number of X-rays excited in the absorber (and efficiently detected) is greater than the detected absorption of the higher-energy gamma photons.

Figures 2 and 4 show that for a given absorbing material the slope of the gamma-absorption curve is dependent on both the energy response of the detector and the photon energies emitted by the gamma source used. Unfortunately, nature has not bequeathed a monoenergetic, high-specific-activity, low-energy, conveniently long-lived gamma emitter—although Am^{241}, Tm^{170} and Cd^{109} offer much promise. It is necessary, therefore, to look to the detector as a means of utilizing a relatively intense source emitting at least one low-energy component.

It should be added that excitation of electromagnetic radiation by gamma, beta, or alpha absorption offers an alternate method for obtaining low-energy photons.

Figure 4 shows the lead absorption curves for four different detectors. Increasing negative slopes are seen for detectors with increasing ratio of low-energy response to high-energy response. Fig. 5 shows the calculated half-thickness versus energy for the materials composing these detectors, and Fig. 6 shows calculated values of the fractional gamma absorption that is obtained with the detector dimensions employed in this work.

In evaluating a detector for application to a particular analysis, it is necessary not only to consider the slope of the absorption curve (see Fig. 4) but also the total current and source current-to-background current ratio. The values of these three factors for six different detectors are summarized in Table 3 for the Am-Pu source.

The critical dependence of detector current on applied voltage (Fig. 7) necessitates an extremely stable power supply. To obtain a preliminary evaluation of the precision obtainable in measuring these currents, a series of nine measurements were made over a period of 2 hr. The current produced in the 2-mm NaI(Tl) crystal through a 708-mg/cm² copper absorber was reproducible to a precision of ±0.4% standard deviation for a single measurement. The power supply was a standard Offner scaler power supply that had been converted to supply negative high voltage. The voltage stability of this power supply is not the best obtainable commercially.

An additional variable to be considered in selecting a system to be applied to a given determination is the relation between precision and sensitivity. The 0.4% fluctuation in current at 708 mg/cm², noted previously, corresponds to a 0.3% change in the areal density determined. At 70 mg/cm² of copper, the same 0.4% fluctuation corresponds to a ±3% uncertainty in areal density. In applying the absorptiometric method to the analysis of solutions, the absorption measurements made through a given sample thickness will be more precise (on a percentage basis) at higher areal densities but will be less sensitive (change in current/change in concentration). At a given concentration of the solution to be analyzed, the use of longer absorber path lengths is indicated for an optimum sensitivity-precision relationship. Longer path lengths, however, decrease the source intensity by the inverse square law and thus require a higher-intensity source.

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Production of Iodine-132

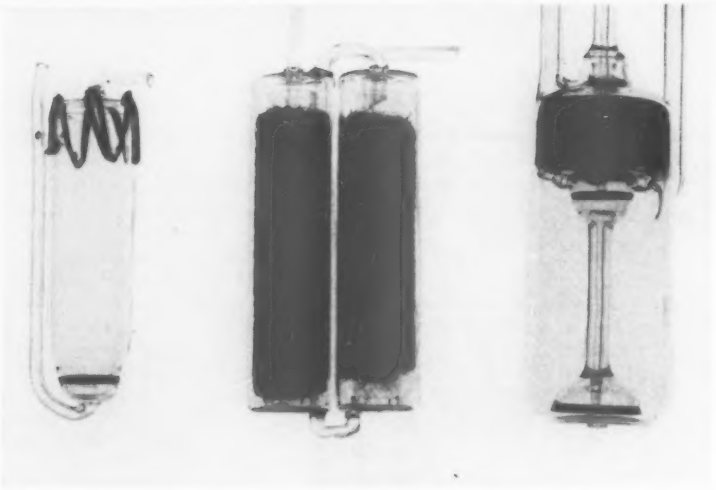

FIG. 1. Glass components of I^{132} shipping unit, with generator at right

Revised equipment and procedures for production and shipment of I^{132} make it available to qualified persons anywhere. Half-life has been accurately determined as 2.33 hr; effective half-life for shipment is 77 hr

By L. G. STANG, Jr., W. D. TUCKER, H. O. BANKS, Jr., R. F. DOERING, and T. H. MILLS
The Hot Laboratory, Brookhaven National Laboratory, Upton, New York

PROCESSES REPORTED two years ago (*1*) have been revised to simplify production of I^{132} and to make it available now for use. This article describes the new production process and a shipping container that, while retaining the advantage of shipping Te^{132} to gain an effective half-life of 77 hr, makes I^{132} extraction simpler for the user.

Iodine-132 possesses certain characteristics that make it potentially superior to I^{131} for some uses. Characteristics of both isotopes are summarized in the table on this page.

The shorter half-life of I^{132} has two distinct advantages and a possible third: (1) it minimizes or entirely obviates the problem of waste disposal, (2) it permits repeat tests or experiments to be made on a given system in a much shorter time than I^{131}, and (3) it may permit the administration of massive doses of radiation without deleterious effects caused by lingering whole-body radiation.

Other differing characteristics are in the energies of the betas and gammas emitted by the isotopes. I^{132} emits beta particles and gamma rays that are considerably harder than those of I^{131}. Since local radiation intensity increases with beta energy, I^{132} might prove to be more effective therapeutically in a system in which its shorter half-life is acceptable and in which its harder gammas are not objectionable. (The potential usefulness of I^{132} in such a system is not limited to thyroid therapy, since tagging of compounds that quickly migrate to diseased areas of the body presents other possibilities. In this connection, the authors have been advised that I^{132} probably will not prove to be the isotope of choice for thyroid therapy because of its short half-life and the relatively slow uptake by the thyroid.) The harder gammas of I^{132} will render its detection in trace amounts easier in some systems.

Parent-Daughter Relationship

A study of the parent-daughter relationship between Te^{132} and I^{132} shows that the I^{132} activity rises to a maximum 12.4 hr after the parent sample of Te^{132} has been freshly cleaned (*1*). Moreover, although the I^{132} has a 2.33-hr half-life, in 12.4 hr it reaches "transient equilibrium" with its parent, 77-hr Te^{132}, so that its "effective" half-life is 77 hr, a fact that simplifies shipping and handling problems.

Isolation of Tellurium-132

Multicurie quantities of tellurium are now isolated by remote control from irradiated uranium and its fission products. The process gives pure tellurium, with an over-all yield of at least 80%. Chemical separation is performed in a "hot cell" behind a foot of steel shielding, and consists of the following steps:

Uranium oxide, U_3O_8, pressed into pellets and wrapped in brass foil, is canned in aluminum and irradiated in the reactor for about ten days. Next, the aluminum jacket encasing the irradiated U_3O_8 is dissolved in a solution of sodium hydroxide and sodium nitrate, and this solution is discarded. The U_3O_8, which consists of about 200 grams of metal as the oxide, is then dissolved in nitric acid.

Inactive tellurium in nitric acid solution is added to "carry" the radiotellurium. Most of the excess nitric acid is neutralized cautiously with sodium hydroxide to the stage where the incipient sodium diuranate precipitate redissolves only slowly; TeO_2 is precipitated by adding an experimentally determined amount of formic acid. The dioxide is filtered and washed with very dilute acid to remove traces of diuranate; then it is redissolved in sodium hydroxide. Next, the solution is filtered to remove any impurities remaining as precipitates. After acidifying the filtrate

FIG. 2. Prototype shipping unit with observation ports

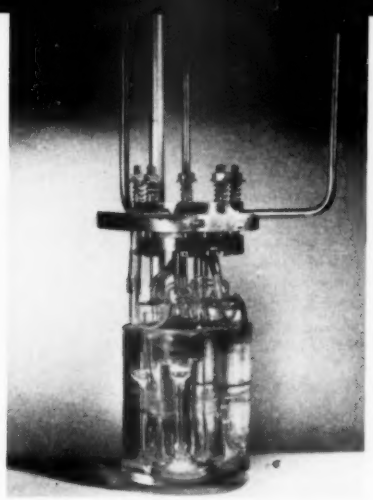

FIG. 3. Generator and hold-up vessels potted in plastic

FIG. 4. Top of shipping unit, showing special three-way valve

with sulfuric acid until it is just acid, elemental tellurium is precipitated with sodium bisulfite solution.

The elemental tellurium is dissolved in nitric acid, and the solution is made basic with sodium hydroxide. TeO_2 is again precipitated with formic acid, and the dioxide is then redissolved in sodium hydroxide. This solution is transferred from the equipment in the hot cell to the iodine "generator," the vessel used to ship the Te^{132}. TeO_2 is precipitated *in situ* by introducing acetic acid. Supernatant liquid is then filtered off and discarded; and the radioactive material is ready for shipment as a dry solid.

In earlier work, the source of the fission products consisted of metallic uranium turnings pressed into slugs. However, considerable processing time is saved by the use of U_3O_8 because it dissolves faster in the acid than the metal does and because it requires a smaller volume of acid, thus rendering the subsequent filtering operation more rapid.

Development of Milking System

To separate and remove I^{132} for use, the volatilization process cited in the original paper (*1*) involved dissolving the $Te^{132}O_2$ in a molten eutectic mixture of LiCl-KCl and sweeping out the generated I^{132} with an air stream. Yields of iodine were good when the vessel containing the molten mixture was glass; however, the mixture rapidly etched the glass, eventually causing it to break.

A study of metals and ceramics that might possibly be used for containers was made. In every case, either the corrosion was prohibitively high or the iodine yield was very low, presumably because of telluride formation. Altogether, more than 28 different materials of vessel construction and 35 different chemical systems were tested (*2*) before eventually abandoning the volatilization technique.

A new milking system has been devised that is not only satisfactory but is even simpler to use than the original one. It involves adding aqueous sodium hydroxide to the shipping unit to dissolve the tellurium dioxide and then reprecipitating the latter by adding acetic acid. Extreme accuracy in measuring reagent volumes is not essential, since the buffering action of the sodium acetate formed tends to keep the *p*H near 5.5, the optimum value for quantitative precipitation of the dioxide. The I^{132} that has grown in the solid tellurium dioxide dissolves in the caustic and is not reprecipitated by the acid. The resulting active iodine solution is then filtered off and is ready for use.

Comparison of I^{132} with I^{131}†

Max. β^- energies (Mev)	*γ energies (Mev)*	*Half-life*
Iodine-131		
0.250 (2.8%)	0.080 (2.2%)	8.04–8.16
0.335 (9.3%)	0.163 (0.7%)	days
0.608 (87.2%)	0.284 (5.3%)	
0.815 (0.7%)	0.364 (80%)	
	0.637 (9%)	
	0.722 (3%)	
Iodine-132		
0.73 (15%)	0.520 (30%)	2.33 ± 0.02
0.97 (20%)	0.620 (6%)	hr
1.16 (23%)	0.670 (100%)	
1.60 (24%)	0.760 (93%)	
2.13 (18%)	0.970 (23%)	
	1.14 (9%)	
	1.41 (13%)	
	1.90 (5%)	
	2.2 (~2%)	

† For I^{131}, all data are from UCRL-1928 (1952). For I^{132}, maximum beta energies are from Finston, Bernstein, and Alburger (BNL); gamma energies were measured by Finston and Bernstein (BNL) with intensities given relative to 0.670 gamma; half-life was measured by authors.

Composition of Product Solution

When the generator is used in the prescribed manner, the product solution measures about 30 ml, has a *p*H of about 5.5, and possesses up to several hundred millicuries of I^{132} activity. It contains about 1.6 gm of sodium acetate, is not toxic, and is compatible with physiological and biological systems.

In systems where the presence of sodium formate or some free formic acid would not be objectionable, formic acid would be preferable to acetic acid because of the still lower solubility of tellurium dioxide.

Contamination of the product solution by inactive tellurium or by Te^{132} is negligible, and amounts to less than 0.5% of the I^{132} activity. The only isotopic impurity in the product I^{132} is I^{131}, and this impurity never exceeds 0.3% of the I^{132} activity at the time of milking. Moreover, there will be no stable I^{127} because none is added and only extremely negligible amounts are formed from Te^{127}; therefore, the iodine is carrier-free.

Shipping Unit

The shipping unit is completely self-contained; the user need furnish nothing more than a vacuum source and a receiver in which to collect the I^{132} solu-

New Radioisotopes Available at Brookhaven National Laboratory

Iodine-132 *(2.33-hr half-life) is now available to qualified users. The method described in the accompanying article makes it feasible to ship a two-to-eight-weeks' supply of this short-lived isotope anywhere in the United States. Prospective users must possess the same qualifications as those required by the Atomic Energy Commission for users of other radioisotopes and must file the same application request for permission to receive and use* I^{132}.

Iodine-133 *(21-hr half-life) is now available in limited quantities. A paper describing the production process for this isotope will be published as soon as development work has been completed.*

Sufficient data have been obtained on which to base a process for pure As^{77}, *free of arsenic carrier, other radioarsenics, and germanium parent, if there should be a demand for this isotope.*

These isotopes are examples of several new ones being developed at Brookhaven by a small group having the general objective of increasing the utility of radioisotopes. Major emphasis has been placed on the development of production methods for isotopes not presently available, but which should be of considerable usefulness if they are made available. The goal of all such processes is to produce relatively large quantities of carrier-free (or very high specific activity) isotopes.

The purpose of this announcement is to stimulate users of radioisotopes to consider the possibility of using isotopes other than those presently available. Inquiries should be directed to the Hot Laboratory Operations Division, Brookhaven National Laboratory, Upton, New York.

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tion as it is withdrawn. When more than 10 mc are to be withdrawn at a given time, a shielded product receiver, which can be mounted on top of the shipping unit, is available. Any desired aliquot can be removed from this receiver, and the remainder can be left to decay within the shield. Besides the shielded receiver, the shipping unit consists of a lead shield housing (1) a special valve, (2) the generator containing the tellurium dioxide, and (3) the purge vessels for retaining the excess iodine.

Figure 1 shows the first radiation shield built to house the I^{132} generator. Operation of the glass equipment within this prototype can be observed through two portholes, made of lead glass. Including the cover, the unit weighs approximately 850 lb. The internal cavity is approximately 4 in. in diameter and 7 in. high, and is surrounded by 4 in. of lead shielding. More than 1 curie of I^{132} can be shipped in this shield; a proportionately lighter shield is used when less than this amount is desired.

Figure 2 shows the glass components that fit inside the shipping shield. On the right is the generator into which the TeO_2 is placed. Within the generator can be seen a central dip tube through which the reagents are added; this tube has a sintered glass disk on the bottom and another near the top. The product solution is withdrawn by sucking it up through the dip tube; at the same time, the TeO_2 precipitate is held back by the frits. The other vessels in Fig. 2 are the "hold-up" vessels, which function to collect and retain excess I^{132} when the generator is purged, thus permitting the I^{132} activity to decay inside the shipping shield.

Figure 3 shows the four vessels mounted together, cast in plastic, and connected to the special three-position valve, which becomes part of the cover of the shipping shield. As can be seen in Fig. 4, this valve has three clearly marked positions: *P*, for product draw-off; *R*, for reagent input; and *H*, for hold-up. When the valve is turned to a given position, the appropriate connections are automatically made. Turning the valve to any intermediate position seals off the entire system.

Life of Generator

Rated generator life is a function of the amount of Te^{132} charged into it and the minimum quantity of I^{132} required from it. Using the described shield, enough tellurium can be charged into the generator so that there will be about 1 curie of Te^{132} present when the shipment is received. Under these circumstances, if the user is interested in only 10 μc of I^{132}, the usable life of the unit would be approximately 54 days.* At Brookhaven, a single charge of Te^{132} has been milked as many as 35 times over a 52-day period, and has yielded 100 mc of I^{132} 15 days after the irradiated uranium oxide has been removed from the nuclear reactor.

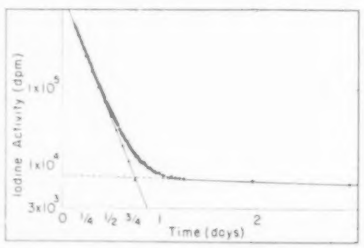

FIG. 5. Decay curve for half-life measurement

Iodine-132 Half-Life

Several very hot samples of I^{132}, fresh from the generator, have been counted at frequent intervals for 24 hr, and less frequently for several days thereafter. When the logarithm of the activity is plotted against time, perfectly straight lines have been obtained for periods of about six half-lives.

Figure 5 shows a decay curve typical of many that have been obtained. The curve appears to be heavy and bumpy because of the great number of experimentally determined points; it flattens out so that its slope corresponds to a half-life of 8 days, because of the small amount of I^{131} present. No other activities are evident. When this 8-day tail is extrapolated back to zero time and subtracted from the composite curve, the steep straight line is obtained, the slope of which gives the half-life of I^{132}.

Nine such curves have been analyzed to give a half-life of 2.33 ± 0.02 hr. It is felt that this value is doubtlessly the most accurate one published. The previously accepted value was 2.4 hr, reported by Abelson (*3*); Hahn and Strassmann gave a value of 2.3 hr (*4*).

* * *

This work was conducted at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission, part of the study being directly supported by the Commission's Division of Biology and Medicine. Dr. Lee Farr and other members of the Brookhaven Medical Department offered helpful advice and encouragement. Testing of the final product and the shipping unit was made possible by the splendid cooperation of Drs. J. E. Rall and Euclid Hanbury of the Sloan-Kettering Institute. Part of this information was presented at the 124th National Meeting, American Chemical Society, Chicago, Illinois, September 11, 1953.

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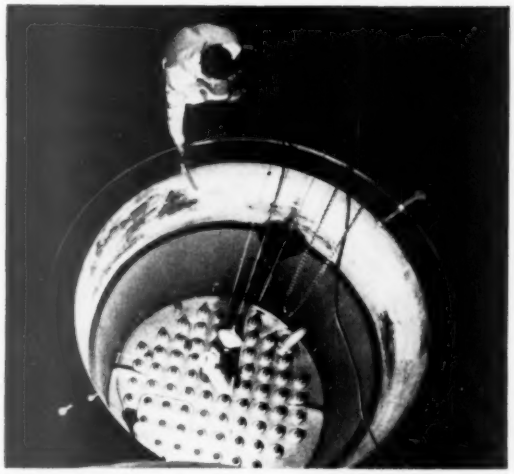
* Calculated as follows: $1c/10\ \mu c = 10^5 \cong 2^{17} = 17$ half-lives $= 1{,}310$ hr $\cong 54$d.



Norwegian-Dutch JEEP Reactor

In a Heavy-Water Reactor:

How Do Gamma Rays Affect Reactivity?

Gamma rays produced by neutron capture in a heavy-water reactor react with deuterium to produce more neutrons. The extent of this reaction and its effect on reactivity is discussed for structural and irradiated materials

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DEUTERIUM'S low photoneutron threshold offers heavy water, which has superior moderating properties, another advantage over graphite as a moderator. This article shows, by calculation and experiment, how photoneutrons affect reactivity of the JEEP reactor (*1*). Two situations are considered—when the source of high-energy gamma rays is inherent in the reactor (originating in fuel elements or structural materials), and when it is introduced from outside.

Perturbation Calculation

Since reactivity perturbation is assumed to be small, we can neglect the contributions from the delayed neutron emitters. According to diffusion theory, the rate of change of the thermal neutron flux in the system is given by

$$\frac{1}{v}\frac{\partial\phi(r,t)}{\partial t} = D\nabla^2\phi(r,t) - \Sigma_a\phi(r,t) + \frac{k}{p}\Sigma_a\phi(r,t)\overline{P_\infty}(B^2) \quad (1)$$

where we consider the fundamental mode of the reactor with buckling B^2. For the unperturbed system, which is in a stationary state, we have

$$0 = D\nabla^2\phi - \Sigma_a\phi + \frac{k}{p}\Sigma_a\phi\overline{P_\infty} \quad (2)$$

We now introduce a high-energy (>2.2 Mev) gamma source into the reactor. Some gamma rays will diffuse out into the moderator where a fraction of them (~0.1%) will be absorbed by the deuterium to produce neutrons. The neutrons will, on the other hand, be slowed down and then diffuse at thermal energies until they are absorbed in the reactor. To simplify the analysis, it will be assumed that the Fourier transform of the infinite slowing-down kernel is the same for the fission neutrons and the photoneutrons and that it is not changed by the perturbation.

As a result of the perturbation, the reactor will no longer be in a stationary state. Let us assume that, in the perturbed system, $\phi'(r,t)$ varies with time according to an exponential function with a period $1/\omega'$ equal to the stable period. This is a valid assumption as long as the variations in ϕ' are small compared to ϕ'.

If the gamma-ray source's strength per unit volume is S and if ξ is the probability that the gamma ray produces a photoneutron in the moderator, we have for the perturbed system

$$\frac{1}{v}\omega'\phi' = D\nabla^2\phi' - \Sigma_a\phi' - \partial\Sigma_a\phi' + \frac{k}{p}\Sigma_a\phi'\overline{P_\infty} + \frac{\partial(k\Sigma_a)}{p}\phi'\overline{P_\infty} + \xi S\overline{P_\infty} \quad (3)$$

where $\partial\Sigma_a$ is the macroscopic absorption cross section per unit volume of the gamma-ray source. The change in k is assumed to be due to a change in f only. Since, on the other hand, f is proportional to $1/\Sigma_a$ the term with $\partial(k\Sigma_a)$ on the right side of Eq. 3 vanishes.

Multiplying Eq. 2 by ϕ' and Eq. 3 by ϕ, integrating over the volume of the reactor, subtracting the two equations, and using Green's theorem, we get

$$\frac{1}{v}\omega' = \frac{-\int\partial\Sigma_a\phi\phi'dV + \xi\overline{P_\infty}\int S\phi dV}{\int\phi\phi'dV} \quad (4)$$

Symbols

$\phi(r,t)$ = thermal neutron flux at the position r at time t

v = average velocity of thermal neutrons

D = diffusion coefficient

∇^2 = Laplacian operator

Σ_a = macroscopic absorption cross section of reactor material

l = average lifetime of a neutron in the reactor

k = thermal neutrons produced per thermal neutron absorbed in infinite reactor

k_{eff} = thermal neutrons produced per thermal neutron absorbed in finite reactor

k_{ex} = change in the neutron inventory during a time l

$\rho_{eff} = k_{ex}/k_{eff}$ = reactivity

p = resonance escape probability

$\overline{P_\infty}(B^2)$ = Fourier transform of infinite slowing down kernel

B^2 = buckling

S = strength per unit volume of gamma-ray source

S' = total gamma-ray source strength

ξ = probability that gamma-ray shall produce a neutron in heavy-water

$\partial\Sigma_a$ = macroscopic absorption cross section per unit volume of source material

$\partial\Sigma_a'$ = total macroscopic absorption cross section of source material

f = thermal utilization

ϕ_i = thermal neutron flux at the position of the sample

ϕ_s = thermal neutron flux during high-level irradiation

$\tau(E_{th})$ = Fermi age of thermal neutrons

$L_1 = D_1/\Sigma_1$

D_1 = average diffusion coefficient for fast netruons

Σ_1 = slowing-down cross section

τ = mean-life of the gamma-emitting isotope

W = reactor power level

For small perturbations we can write

$$\frac{\partial\phi'}{\partial t} = \frac{k_{ex}}{l}\,\phi' \qquad (5)$$

or

$$\omega'\phi' = \frac{k_{ex}}{k_{eff}}\,\Sigma_a v\,\frac{k}{p}\,\overline{P_\infty}\phi'$$

Multiplying by ϕ and integrating over the reactor volume, the result is

$$\rho_{eff} = \frac{k_{ex}}{k_{eff}} = \omega'\,\frac{\int\phi\phi' dV}{\overline{v\overline{P_\infty}}\int\frac{k}{p}\,\Sigma_a\phi\phi' dV} \qquad (6)$$

Inserting ω' from Eq. 4, we get

$$\rho_{eff} = \frac{1}{\overline{P_\infty}\int\frac{k}{p}\,\Sigma_a\phi\phi' dV}\,[\xi\overline{P_\infty}\int S\phi dV - \int\partial\Sigma_a\phi\phi' dV] \qquad (7)$$

For small perturbations, ϕ can be substituted for ϕ'. Furthermore, let us assume that the extension of the source is so small that ϕ does not vary over its volume. For simplicity we will also assume that ϕ does not vary over the volume of the photoneutron source. Thus we get

$$\rho_{eff} = \frac{\phi_s^2}{\overline{P_\infty}\int\frac{k}{p}\,\Sigma_a\phi^2 dV}\left[\frac{\overline{P_\infty}\cdot\xi\cdot S'}{\phi_s} - \partial\Sigma_a'\right] \qquad (8)$$

where S' and $\partial\Sigma_a'$ are now the integrated source strength and macroscopic cross-section. This expression is in agreement with Littler's result (*2*).

The constant in the denominator of the first factor in Eq. 8 can be determined by inserting a known absorber to a point in the reactor where the neutron flux is known. The change in reactivity is deduced from the observed stable period obtained when the absorber is withdrawn from the reactor. If ϕ_0 is the slow neutron flux at the center of the reactor and ϕ_i is the flux at the position where the sample is introduced, we have for JEEP

$$\rho_{eff} = 1.7\times10^{-4}\cdot\frac{\phi_s^2}{\phi_0^2}\left[\frac{\overline{P_\infty}\cdot\xi\cdot S'}{\phi_s} - \partial\Sigma_a'\right] \qquad (9)$$

Adopting the Fermi-age continuous slowing-down treatment (*3*) we get

$$\overline{P_\infty}(B^2) = pe^{-B^2\tau(E_{th})}$$

On the other hand, the two-group-diffusion slowing-down treatment gives

$$\overline{P_\infty}(B^2) = \frac{p}{1+L_1^2B^2}$$

The numerical constants for JEEP are

$$p = 0.84$$
$$B^2 = 5\times10^{-4}\ \text{cm}^{-2}$$
$$\tau(E_{th}) = 110\ \text{cm}^2$$
$$L_1^2 = 137\ \text{cm}^2$$

Thus we get

$$\overline{P_\infty}(B^2) = 0.79$$

Sources from Outside

The absorption of a neutron by a sample inserted into the reactor usually results in the instantaneous emission of one or more high-energy gamma rays. As indicated earlier, gamma rays above 2.2 Mev have a probability of about 10^{-3} of producing photoneutrons. Thus, the contribution to the reactivity due to the gamma rays is only a few tenths of one per cent of the suppression in reactivity due to the absorption.

Theory. If the gamma-ray emission is delayed with respect to the absorption process and the power level of the reactor is changed, we might get a pronounced effect. Let us assume that a sample has been irradiated in a neutron flux ϕ_i for a time T. If τ is the mean-life for the emission of the high-energy gamma ray, the total source strength S' at a time t after the end of the irradiation will be given by

$$S' = \phi_i\,\partial\Sigma_a'\,(1-e^{-T/\tau})e^{-t/\tau} \qquad (10)$$

For $T \gg \tau$ and $t = 0$ we get for the perturbed reactivity

$$\rho_{eff} = 1.7\times10^{-4}\left(\frac{\phi_s}{\phi_0}\right)^2\partial\Sigma_a'\left[\overline{P_\infty}\xi\,\frac{\phi_i}{\phi_s} - 1\right] \qquad (11)$$

Since $\overline{P_\infty}\xi$ is of the order of 10^{-3} it is apparent from Eq. 11 that in order for the source term to become important $\phi_i/\phi_s \geq 10^3$.

Experiment. As an example, we have irradiated 190 gm Na_2CO_3 at a position in the reactor where the neutron flux was 40% of that in the center. The (n,γ) reaction in Na^{23} leads to Na^{24}, which decays with a half-life of 14.9 hr. A gamma ray of 2.758 Mev is emitted in the decay.

The sample was irradiated for 40 hr with the reactor at a power level of 200 kw. The power level was then reduced and the change in reactivity was meas-

ured by oscillating the sample between the position where it was irradiated and the outer surface of the biological shield. At power levels below about 1 kw, the reactor was running at a negative reactivity with the sample in both positions. This was due to the source of delayed photoneutrons released in heavy water by gamma rays from the fission products (*4*). When the sample was oscillated, the change in power level was recorded. This was translated into changes in reactivity by comparison with the effect of a displacement of the calibrated control plates. When the power level was at 40 watts, the change in reactivity was $+10^{-4}$; at 400 watts, $<10^{-5}$; at 4 kw, -10^{-5}.

Comparison. The total macroscopic cross-section $\partial\Sigma_a'$ for the Na^{23} (n, γ) Na^{24} reaction in the sample was 1 cm^2. Due to self-screening, however, the effective value of $\partial\Sigma_a'$ was lower. According to Eq. 11, we have for this sample

$$\rho_{\text{eff}} \simeq 10^{-5}\left(\overline{P_\infty}\cdot\xi\cdot\frac{W_i}{W}-1\right) \quad (12)$$

where W_i and W are the power levels of the reactor during irradiation and following experiments, respectively. The observed data agree with this formula if we insert a value for $\overline{P_\infty}\cdot\xi = 2\times10^{-3}$. This agrees with the value calculated from the Compton scattering and photoneutron cross-sections in D_2O.

Calibrating neutron sources. It has been shown by Littler (*2*) that Ra-Be neutron sources can be calibrated by introducing them in a reactor and measuring the pertubation in the reactivity at different power levels. We have performed similar measurements with two 100 mc Ra-Be sources. Their macroscopic absorption cross sections and source strengths were $\partial\Sigma_a' \simeq 0.5$ cm^2 and $S' = 1.4\times10^6$ n/sec, respectively. The slow neutron flux at the reactor center is 3×10^6 n/cm^2/sec/watt. Therefore, we see from Eq. 9 that the reactor has to be operated at about 1 watt if the source term is to become noticeable when the Ra-Be is placed at the center. At such a low power level, the signal from the source is swamped by the background in our experimental arrangement. Furthermore, the photoneutrons due to the fission products influence the measurements up to power levels of several hundred watts. Thus with our D_2O-moderated reactor, which is normally run at 200 kw, it is not possible to calibrate Ra-Be sources below 1 c. Even with 10 c source strengths it is doubtful whether a calibration with an accuracy of 10% can be performed.

Inherent Sources

When a neutron is absorbed in the reactor, whether it is in the fuel elements or in structural materials, one or more gamma rays are usually emitted. In the fission process itself, about 5 Mev is released as prompt gammas (*5*). Since the transition probability increases very rapidly with the energy of the gamma ray, one would expect that each gamma would take away as much energy as possible from the nucleus without violating the selection rules. However, the fission products are de-excited by first emitting neutrons, which probably leaves the products in a state of low excitation. This is in agreement with experiments that yield an average value for the energy of gammas emitted in fission as about 1 Mev (*5*).

Since about 40% of the neutrons in the reactor are absorbed to produce fission of U^{235}, only about 8% produce (n, γ) reactions in U^{235}. According to Motz most of these gamma rays are also below 2 Mev (*6*).

About half of the neutrons are absorbed in the process U^{238} $(n, \gamma)U^{239}$, partly in the resonance region and partly as slow neutrons. The gamma rays emitted in these reactions have, to our knowledge, not been examined in detail. Kinsey *et al.* have measured the gamma-ray spectrum for (n, γ) reactions in a number of heavy elements (*7*). There are usually some gammas emitted with an energy above 2 Mev, but their intensities vary from element to element.

Finally, a few per cent of the neutrons are absorbed by structural materials and the moderator. Gamma rays emitted in the neutron capture of Al are mostly above the binding energy of the deuteron (*8*). The H^2 $(n, \gamma)H^3$ reaction yields a 6.244-Mev gamma (*9*).

To sum up, we have seen that only in a few per cent of the cases in which neutrons are absorbed in the reactor will a gamma above 2.2 Mev be emitted. The figures are uncertain due to a lack of experimental information. Thus, we are in the process of measuring high-energy gamma rays from the reactor's materials.

However, we have earlier seen that such gamma rays have only about a 0.1% chance of producing photoneutrons. Thus we conclude that the contribution to the reactivity of a D_2O-moderated reactor due to "prompt" gamma-rays is scarcely above 0.1%.

The high-energy gamma rays emitted at a time delayed with respect to the fission process have been investigated by Bernstein *et al.* (*10, 11*). If one waits for more than 10 hr after the end of neutron irradiation, the experimental data can be reproduced theoretically by means of existing information on gamma rays emitted from fission fragments (*12*). For shorter waiting times, however, the results are rather uncertain. Bernstein *et al.* conclude from their measurements that 2.5 delayed photons are emitted per fission with an energy above the binding energy of the deuteron. Their contribution to the reactivity of a heavy-water reactor is $\leq 16\%$ of that of delayed neutrons, or $\leq 0.12\%$ depending on self-absorption in the fuel elements.

If the lifetime of the nucleus that emits the gamma rays is τ and the neutron-absorption cross section of the nucleus is σ, we have for the ratio of decay to neutron absorption

$$R = \frac{\text{decay probability}}{\text{neutron abs. prob.}} = \frac{1/\tau}{\sigma\phi} = \frac{1}{\tau\sigma\phi} \quad (13)$$

where ϕ is the neutron flux at the position of the nucleus. For $\sigma = 10^{-24}$ and $\phi = 10^{11}$ we have

$$R = \frac{10^{13}}{\tau}$$

Thus the nucleus has to be very long lived to be lost by neutron absorption. If both σ and ϕ are large, however, one might find that a long-lived gamma-ray emitter's contribution to reactivity varies with the reactor's power level.

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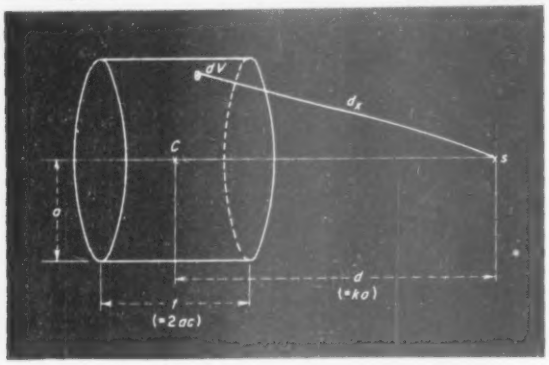

1 CYLINDRICAL IONIZATION CHAMBER is diagrammed with distances labeled to define terms used in expressions for calculating ionization density. Thus, S = source; C = geometrical center of chamber; a = chamber radius; t = chamber height; d = source-chamber distance; d_x = distance from source to dV, a differential element of chamber volume; c = chamber height expressed in units of chamber diameter, i.e., $t/2a$; and k = source-chamber distance expressed in units of chamber radius, i.e., d/a

Optimum Shape for Cylindrical Ionization Chambers

Correction factors for geometry are derived to permit calculations of true ionization density from chamber readings with source on chamber axis. Minimum corrections are required when ratio of cylinder height to diameter is 0.75 or 0.80

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IN MOST PROBLEMS of radiation dosimetry involving point sources, the ionization density at distance d from the source, $i'(d)$, is computed from

$$i'(d) = I(d,V)/V \qquad (1)$$

where $I(d,V)$ is the measured ionization current in a chamber of volume V having its center at a distance d from the source. Equation 1 is incorrect when the chamber's linear dimensions are not sufficiently small compared to d. In this case, if the inverse square law applies to all points within the chamber, the true ionization density, $i(d)$, at distance d is obtained from

$$i(d) \int_V \frac{dV}{d_x^2} = I(d,V)d^2 \qquad (2)$$

where dV is an element of the chamber volume, and d_x is its distance from the source. Accordingly, the true ionization density can be expressed in terms of the computed ionization density, $i'(d)$, and a correction factor, R, as

$$i(d) = i'(d)/R = I(d,V)/RV \qquad (3)$$

where R, as determined from Eqs. 1 and 2, is

$$R = \frac{d^2}{V} \int_V \frac{dV}{d_x^2} \qquad (4)$$

For most chamber shapes and orientations, computation of R requires numerical integration. For a sphere, the function is integrable and appears in the radiological literature (*1*). Mayneord and Roberts (*2*) have shown that the case of a cylinder with the source on its axis also has an exact solution.

Correction Factor, External Source

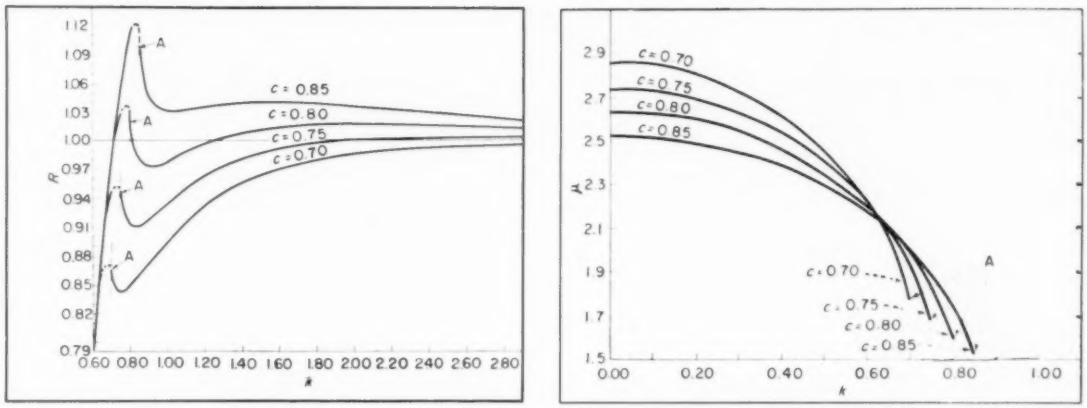
Handling of deviations from the inverse square law, as in Eq. 4, is cumbersome at best. Hence, it is desirable to design an ion chamber that requires a minimum correction factor, R, even at distances that are very small compared to the chamber dimensions. It can be seen qualitatively from an analysis of the two extreme cylindrical shapes that this might be possible. A pencil-like chamber with the source located on the axis will read too high, because the excess ionization in those elements of volume for which d_x is less than d is greater than the ionization deficiency in those elements for which d_x is greater than d. Conversely, a shallow pill-box chamber with the source on the axis has most of the ionized volume at distance d_x greater than d; hence, i' is less than i.

It is possible to combine these extreme cylindrical shapes into a shape giving minimum deviation from the inverse square law. If the definitions in Fig. 1 are used, then $V/d^2 = \pi a^2 t/d^2$, and Mayneord and Roberts' result takes the form

$$S = \int_V \frac{dV}{d_x^2} = \pi \left\{ \left[\left(d + \frac{t}{2}\right) \ln \frac{a^2 + \left(d + \frac{t}{2}\right)^2}{\left(d + \frac{t}{2}\right)^2} + 2a \tan^{-1} \frac{d + \frac{t}{2}}{a} \right] - \left[\left(d - \frac{t}{2}\right) \ln \frac{a^2 + \left(d - \frac{t}{2}\right)^2}{\left(d - \frac{t}{2}\right)^2} + 2a \tan^{-1} \frac{d - \frac{t}{2}}{a} \right] \right\} \qquad (5)$$

The correction factor, R, now has the value

$$R = S\left(\frac{d^2}{\pi a^2 t}\right) \qquad (6)$$



2 CORRECTION FACTORS for ionization density measurements are used when chamber dimensions are not sufficiently small compared to d. When source is outside chamber and on its axis, R is correction factor used (left). R is dimensionless and represents ratio of computed ionization density to true ionization density, i.e., $i'(d)/i(d)$. A indicates position of chamber's front face. When source is inside chamber and on its axis, μ is correction factor used (right); μ represents ratio of computed ionization density at distance $d = ka$ to the true ionization density at standard distance $d_0 = a$

which can be put in parametric form by expressing the height of the chamber and the source-chamber distance in units of the chamber radius, i.e., $t = 2ac$ and $d = ka$ (Fig. 1). By combining Eqs. 5 and 6 with these parameters, one obtains

$$R = \frac{k^2}{2c}\left\{\left[(k+c)\ln\left(\frac{1}{(k+c)^2}+1\right) + 2\tan^{-1}(k+c)\right] - \left[(k-c)\ln\left(\frac{1}{(k-c)^2}+1\right) + 2\tan^{-1}(k-c)\right]\right\} \quad (7)$$

Examination of Eq. 7 shows that R is independent of chamber size and is a function only of k and c. Accordingly, the problem is to determine a value of c such that R is independent of k and equal to unity. Unfortunately, c enters the formula in the arguments of transcendental functions, and it is therefore impossible to solve the equation for c explicitly. The only alternative is to compute the values of R as a function of k for various values of c. Figure 2 shows the results of such calculations. When $c = 0.80$, the source can be brought all the way to the front face of the chamber with less than 3% maximum deviation from the inverse square law. Also, when $c = 0.75$, the source can be brought to a distance from the chamber center equal to 1.6 times the radius with the readings showing less than 1% maximum deviation from the inverse square law.

Correction Factor, Internal Source

Occasionally, it may be desirable to place the source within the chamber. In this case, when d equals zero, R equals zero and $i(d)$ goes to infinity. This difficulty vanishes, however, when the ionization density $i(d_0)$ is computed at some finite distance d_0, since the ionization density is then readily computed by means of the inverse square law, according to the familiar expression

$$i(d_0) = i(d)d^2/d_0^2 \quad (8)$$

Substituting in Eq. 8 the value of $i(d)$ shown in Eq. 3 and representing Rd_0^2/d^2 by μ, one obtains

$$i(d_0) = I(d,V)d^2/RVd_0^2 = I(d,V)/\mu V = i'(d)/\mu \quad (9)$$

Calculation of the true ionization density at a distance d_0, when the ionization density $i'(d)$ is measured with the source placed at a distance d from the center of the chamber, can be accomplished using Eq. 9. The correction factor, $\mu = Rd_0^2/d^2$ is analogous to R in Eq. 3; it retains, however, the advantage of being finite when $d = 0$ since R is proportional to d^2 (Eq. 7), and it can be computed easily in parametric form from Eq. 7. Figure 2 shows μ as a function of k when $d_0 = a$. If d_0 does not equal a, the required values of μ can be obtained by multiplying the given values by d_0^2/a^2. It is therefore possible, by adjusting the size of the chamber (i.e., the value of a) or by proper choice of the standard distance d_0, to obtain a value of μ equal to unity for any desired source position, such as the center of the chamber.

In the flat portion of the curves (Fig. 2), when c equals 0.75 or 0.80, the correction factor μ varies by less than 1% for displacements of as much as 10% of the chamber radius. Thus, accurate centering of the source along the axis is not critical, and these two shapes are at least as satisfactory with an internal source as with an external source.

Limitations

It must be emphasized that the computations reported deal only with geometrical factors involved in such measurements. In addition, the computations have been made only for the case of a point source on the axis of the cylinder. However, it may be noted that by the principle of reciprocity, when the chamber is a "point" on the axis of a cylindrical source, these results apply in detail, subject only to the condition that absorption and scattering are negligible in the source as well as in the medium and in the chamber walls.

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Autoradiographic Studies of Surface Detail with Chromium-51

A unique approach combines methods of vacuum evaporation, shadow casting, and autoradiography. Details of metal surface structure are determined by a nondestructive technique to better than 40 microns in preliminary studies

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EARLIER WORK involving the vacuum evaporation of P^{32} and I^{131} salts (*1, 2*), as well as metallic Cr^{51} and Au^{198}, showed that tracers could be used to measure very thin evaporated-metal films (*3–5*). The technique provides an elegant tool for the exact calculation of condensate mass per unit area. Autoradiography proved a useful adjunct to such thin film studies (*6, 7*), and examination of autoradiographs of the condensing surfaces showed that fine detail was reproduced in the developed emulsion wherever the vapor beam impinged obliquely.

The method used is identical in its first step to the "shadowing" used in electron microscopy (*8–10*), wherein an evaporated metal film is obliquely "cast" onto the specimen surface. The mechanism is illustrated and described in Fig. 1. After the evaporated film has been applied, its configuration can be studied through its autoradiographic response. The schematic illustration in Fig. 2 depicts the gross apposition technique (*11–14*), with surface *B* and its condensed radioactive layer in apposition to the nuclear emulsion. Resolution of inhomogeneities in areas having recessed horizontal films (e.g. above *t*) presumably will be poor (*15*). Vertical structures show intense autoradiographic darkening of the emulsion, whereas obliquely oriented surfaces of promontories and valleys show intermediate, minimum, and zero contrast with the emulsion background fog (*11*).

Experimental Method

In testing this technique, clean copper disks were mounted on supports on an evaporation table, as shown in Fig. 1, and oriented to receive obliquely spec-pure chromium tagged with Cr^{51} (*16*), which emanated from the crucible.*

Figure 2 shows the method used to obtain an autoradiographic exposure of the Cr^{51} surface. Medium lantern slide (m.l.s.) emulsion was selected because of its convenience and relatively small grain size. The table on this page offers a comparison of this emulsion with NTB_3 and X-Ray No-Screen.

Exposures were made at room temperature, and for the Cr^{51} used, lasted about a month (*17–19*). A good autoradiographic response was obtained with this exposure for a copper disk, 2.48 cm in diameter, uniformly coated with Cr^{51} at an impingement angle of about 15 deg; the disk registered about 500 cpm when mounted 1 mm from the mica end-window of a TGC-1 G-M tube.† This is a rough rule and applies only to autoradiographic response of the horizontal faces. Depending upon the obliqueness of evaporant impingement and the height of the structures to be studied, this rule must be altered empirically to obviate overexposure by those faces normal to the beam. Film thicknesses used were always less than 1,000 Å.

Resolution Study

Figure 3 shows the gross agreement obtained in defining surface detail, using a light photograph and an autoradiographic print. The Cr^{51} deposit is heaviest on the side where the beam originates, giving rise to the light areas on the print. At the disk edge on the crucible side, the halo effect is characteristic and stems from the heavy condensate on this deep vertical face. Slight elevations (termed "furrows") resulting from the groove-cutting process cause the flat disk surface and the emulsion to be separated by about 5 to 10 mils; thus, virtually no detail is obtainable from the valley portions.

* The Cr^{51} had a specific activity of 5 mc/gm and was free of radioactive contaminants.

† Efficiency may be improved with a TGC-8 G-M tube, obtainable from Tracerlab, Inc., Boston, Mass.

Emulsion Characteristics

Type	*Sensitivity*	*Grain size (microns)*	*Resolving power*	*Fog*
Medium lantern slide	Medium	0.5–1.0	Good	Medium
X-Ray, No Screen	High	0.5–8.0	Very poor	High
NTB_3	High	0.2–0.3	Good	Medium

To define the available resolution of this system, a copper disk was cut with spiral grooves, using a precision lathe (Fig. 4). The special tool used produced a minimum furrow on either side of the cut; hence, the disk surface displayed a series of flat plateaus separated by concave valleys. When counted as previously described, the disk registered 1,070 cpm. Both edges of the groove are well-defined, indicating a resolution of about 80 μ (Fig. 4).

In contrast to Fig. 3, the valleys in Fig. 4 are little more than 1 mil from the emulsion. Accordingly, some information on valley detail is forthcoming on close inspection. It is possible from the enlargement (Fig. 4, right) to reconstruct the groove's cross-section, including the fact that a very small furrow of varying height (< 1 mil) exists on either side of the groove.

Further studies have indicated that greater resolution is attainable. Autoradiographic prints of copper disks, with grooves spaced 127 μ apart and with a groove width less than one-half this, have indicated an ultimate resolution exceeding 40 μ. A histologic resolution of 2 μ has been reported (*15*).

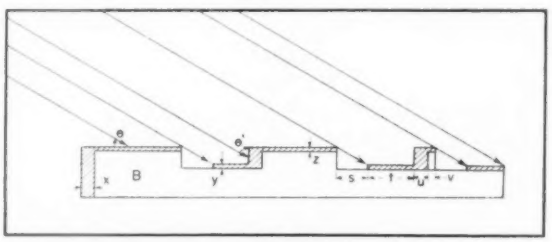
Use of fine-grain emulsion, such as Kodak NTB, NTB_3, and NTA (*22–24*) with a grain size of 0.2 to 0.3 μ, may improve resolution (*14, 25*), and a β- or α-emitting isotope (*26, 27*) of low energy when used with one of the familiar emulsion techniques—e.g., the Pelc stripping method (*28, 29*) or the Belanger coating technique (*30*)—may resolve the valley surface detail. The method has shown good contrast for structures 25 μ in height. Possibility of a chemographic reaction (*31–33*) between the condensate or base metal and the emulsion is an unreported field and must be investigated for each material used.

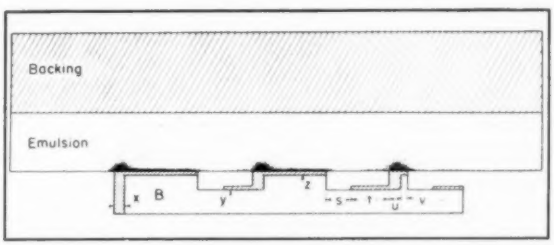
To demonstrate the effect of structure orientation relative to the incident beam, a copper disk was cut with radial lines as shown in Fig. 5. The Cr^{51}-coated disk registered 1,278 cpm when mounted in the usual way. Exposure was for 41 days. Structures along the beam direction are difficult to interpret compared to those positioned at right angles to the beam. The abrasion exposure (solid arrow) represents the most frequent artifact encountered when working with metals, but it is easy to recognize.

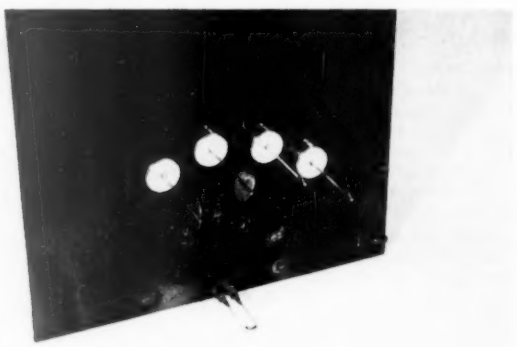
Summary

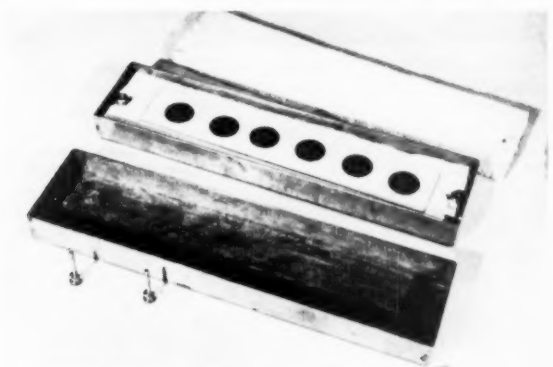
Evidence for resolution of surface detail exceeding 40 μ has been demonstrated using Cr^{51} with m.l.s. emulsion. It is conceivable that a resolution of about 5 μ may be achieved by using

EXPERIMENTAL TECHNIQUE



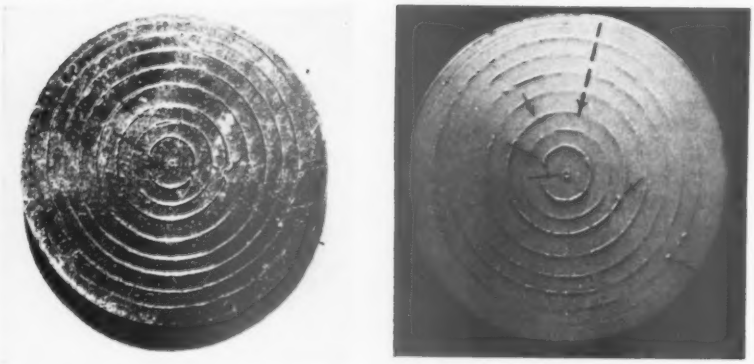




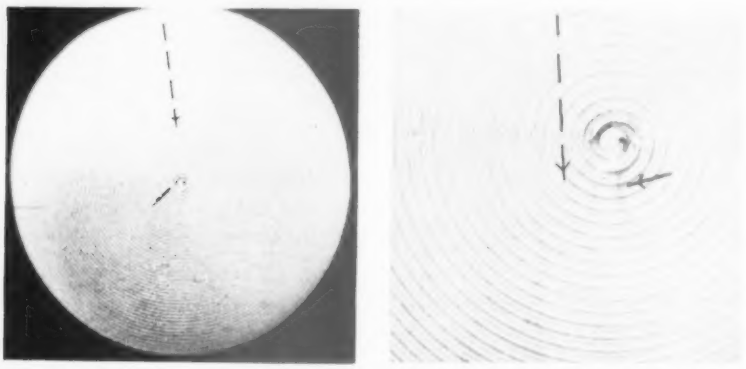


1 VACUUM DEPOSITION METHOD "casts" source metal from high-temperature crucible obliquely on specimen surface. Long oblique arrows (top) represent molecular beam emanating from metal. Metal vapor condenses on cool inhomogeneous surface, *B*, build-up being represented by shaded section with thickness proportional to sine θ. Thinnest films (*y* and *z*) deposit on horizontal surfaces; vertical faces condense thicker layers (*u* and *x*), proportional to sine θ'; and promontories cast "shadows" devoid of metal (area *s*). In experimental set-up (bottom), copper disks are mounted on 6.2-cm supports to receive evaporant obliquely from conical, 7-turn 0.025-in. tungsten-wire crucible. Cr·Cr^{51}, evaporated from crucible, deposits on disks. Varying angles and thicknesses of Cr are thus studied

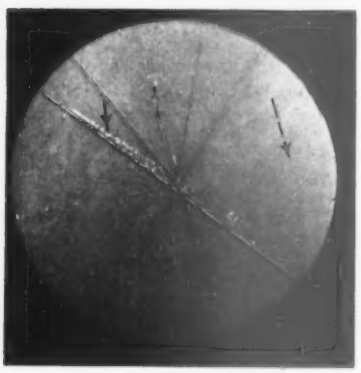
2 AUTORADIOGRAPHS of condensed film are obtained by gross apposition method, using nuclear emulsions (top). Groupings of black specks represent grains rendered developable by emanations from radioactive film. Thicker layers, *u*, show most intense photographic effect; thinner layers, *v*, show less effect; recessed horizontal films, *t*, being relatively remote from emulsion, display least effect; and shadowed areas, *s*, produce no image. Light-tight brass exposure box houses disks with Cr^{51} surfaces placed face down on 2-in. by 10-in. medium-lantern-slide emulsion plate (bottom). Plate is positioned on sponge rubber sheet in housing base; another rubber blanket is pressed firmly over disks to hold them in place and insure intimate contact with emulsion. Top is screwed down to seal contents and maintain uniform pressure



3 SURFACE TEXTURE of copper disk is shown with good agreement between light photograph (left) and autoradiographic print (right). Five short arrows denote distinctive structures in the concentric grooves that score disk. Grooves are 2 to 10 mils deep and 5 to 15 mils wide. In photograph at left, light strikes disk at 10-deg angle from same direction as used for molecular beam, shown by broken arrow in print at right. Cr·Cr^{51} beam was evaporated from 90-deg, conical, 7-turn crucible, using 7-deg impingement angle and 10-cm crucible distance. Autoradiograph (right) was obtained by gross apposition method using m.l.s. emulsion and about two months' exposure time. Light areas represent Cr^{51} concentrations; dark areas are presumably free of Cr^{51} (20, 21). An over-all Cr^{51}-condensate gradient is noted in following line of broken arrow across disk. Abrasion exposures appear as clear areas



4 SPIRAL GROOVES cut in copper disk with precision lathe are used to define resolution attainable from autoradiographic technique. Semicircular grooves, 1 mil deep and about 80 μ wide, are 254 μ apart. Cr·Cr^{51} (25 mg) was evaporated from 90-deg, conical, 7-turn crucible using 15-deg impingement angle and 7-cm crucible distance. Autoradiographic exposure of m.l.s. plate was 39 days, development at 2° C for 0.5 min in D-72, diluted 2:1. Broken arrow indicates evaporant line-of-flight. Autoradiograph (left) shows well-defined groove edges and some valley detail; lack of definition at periphery indicates poor emulsion contact. Enlargement (right) shows some fine structure in groove and on furrow bordering both sides of cut. Very light areas represent abrasion exposures. Grooves, being shaded from Cr^{51} beam, are characterized by darker lines. Small lens-tissue fiber caught at disk center throws shadow (arrow) across spiral



5 ORIENTATION OF SURFACE STRUCTURE relative to incident beam affects contrast obtained in autoradiographic print. Copper disk, grossly scribed with radial lines of about equal depth, is coated with Cr^{51} at 11-deg impingement angle. Structures (broken arrow) with main axis along line-of-flight show poor contrast, whereas furrows at about 90 deg to beam direction show greatest contrast. Abrasion exposure (solid arrow) parallels most well-defined scribe

an isotope with emissions of other energy than the soft γ-rays associated with Cr^{51}.

The gross apposition technique (*34–36*) is simple and gives good topography for orientation. Disadvantages include resolution that is frequently poor because of bad contact, spurious abrasion exposures, and mechanical and thermal movement during exposure, which is magnified by techniques used for high magnification study.

* * *

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Fast-Neutron Dose in a Large Tissue-Equivalent Phantom

Good agreement is found between dose rates obtained when irradiating a large phantom with a Po-B point source and those calculated by Snyder and Neufeld. An empirical exponential equation is given to express the dose rate

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To CHECK Snyder's and Neufeld's calculation† of dose received by tissue from a broad beam of fast neutrons, a slab phantom was irradiated with a Po-B source.

In making their calculation, Snyder and Neufeld (*1*) assumed that fast neutrons were striking normally and uniformly on the surface of a slab of tissue 30 cm thick and infinitely wide. In one case the neutron energy spectrum had a maximum near 2.5 Mev. An experimental check of the neutron dose was carried out for this case since a source of neutrons with approximately the same energy spectrum was available in Po-B. The slab phantom, while not altogether suitable as an approximation to the human body, has several advantages. It may be used as a matrix into which small animals can be placed for neutron irradiation. The dose given for any position inside the phantom should closely approximate the dose given a small animal

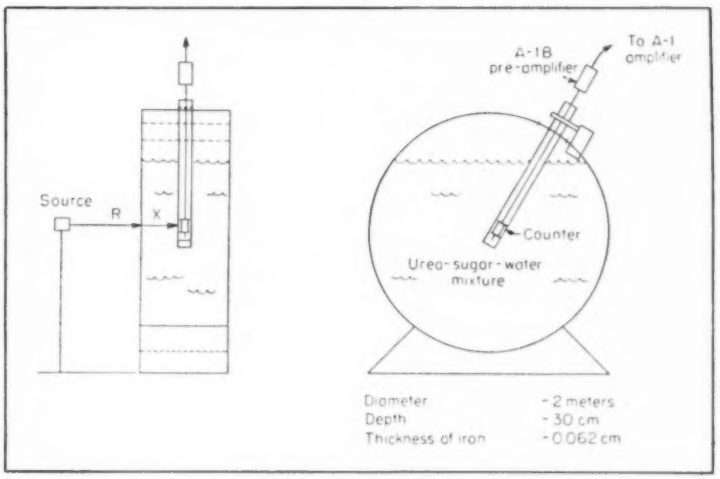

FIG. 1. Arrangement of phantom, source and neutron dosimeter

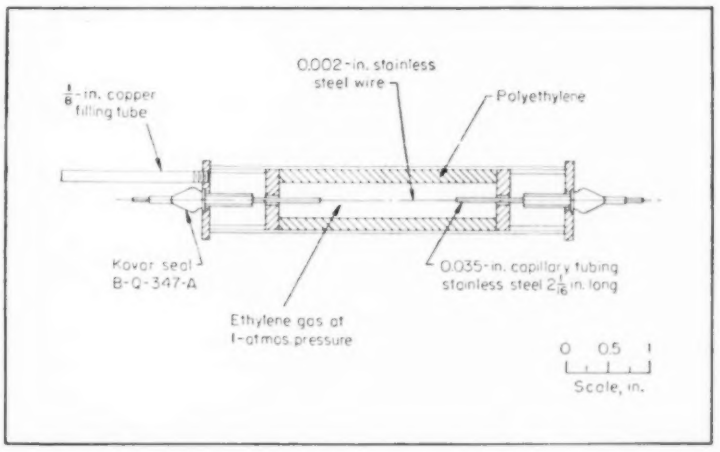

FIG. 2. Design of proportional counter

* Summer research participant, University of Georgia, Athens, Georgia.

† Accepted as the basis for maximum permissible doses of neutrons by the International Commission on Radiological Protection, on recommendation of Subcommittee IV on Protection Against X-Rays above 3 Million Volts, β-Rays, γ-Rays, and Heavy Particles, Copenhagen, Denmark, July 1953.

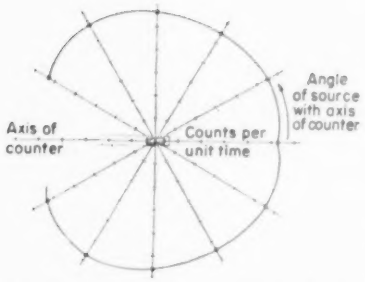

FIG. 3. Directional dependence of proportional counter

placed in that position if precautions are taken to eliminate any large discontinuities in the phantom material. Also, the slab form lends itself well to neutron shielding problems in those cases where it is considered advisable to shield with a wall of hydrogenous material.

Method

As an approximation to Snyder's infinite slab of tissue, a cylindrical tank (30 cm thick and 200 cm in diameter) was constructed of 0.025-in. mild steel and was filled with a tissue-equivalent solution. Figure 1 shows the arrangement of the source, phantom, and counter.

The phanton solution contained nearly the same relative amounts of hydrogen, oxygen, carbon, and nitrogen found in average wet human tissue (*2*). The compounds used to supply these elements were water (1,285 lb), commercial sucrose (443 lb), urea (157 lb), and a pound of thymol to prevent bacterial growth. The solution thus contained 10% hydrogen, 74% oxygen, 12% carbon, and 4% nitrogen.

The dosimeter was a proportional counter (*3*) (Fig. 2) in which the counting volume was filled with ethylene and lined with polyethylene to conform to the Bragg-Gray principle. The counter was connected to an A1B preamplifier from which the signal was fed to an A1 amplifier and then to a pulse integrator (*4*). A coaxial pipe, which had a capacitance of only 16 $\mu\mu$fd, connected the counter to the preamplifier. Voltage gain of the linear amplifier and collector voltage on the counter were adjusted so that the dosimetry system was insensitive to gamma rays. The proportional counter had very little directional sensitivity, as is shown by the plot (Fig. 3) of the counting rate when the neutron source is moved along the arc of a circle of 30-cm radius with the counter at the center of the circle.

The neutrons were obtained from a physically small Po-B source, the spectrum of which has a maximum near 2.5 Mev (*5*). For this particular source, the first collision tissue dose per neutron per cm^2 was 3.54×10^{-9} rep (*6*) (1 rep = 93 ergs/gram absorbed in soft tissue). All dose measurements are normalized (on the basis of a 138-day half-life for Po) to correspond to the source strength as it was on the day these experiments were initiated. At that time the neutron flux at 1 cm in air was 2.05×10^6 cm^{-2} sec^{-1} (7.26×10^{-3} rep sec^{-1}).

Data

The data are presented in Fig. 4 as they were obtained from the dosimeter-integrator. R represents the distance in air between the source and the face of the phantom, and X is the depth in the phantom at which the counter was placed. The data were analyzed by the "least-squares" method and fitted to a curve of the form

$$D = \frac{D_0 B e^{-X/L}}{(R+X)^2} \qquad (1)$$

where D represents the dose rate under the conditions established by any particular value of R and X, D_0 is the "first-collision dose" at 1 cm in air from the source, B is the buildup factor due to the presence of the phantom material in the radiation field, and L is the distance in the medium required for the dose rate to drop by a factor of e^{-1} (L is sometimes referred to as the relaxation length). In Fig. 4, the solid lines represent the "least-squares" fit of all data for all values of R and X, with the exception of the first three points of the curve for R = 6 cm. These three points were probably low due to the mechanical limitations of the integrator in measuring such high dose rates. Actually, it was mathematically expedient to minimize the squares of the differences of the logarithm function of Eq. 1 rather than the equation itself, i.e.

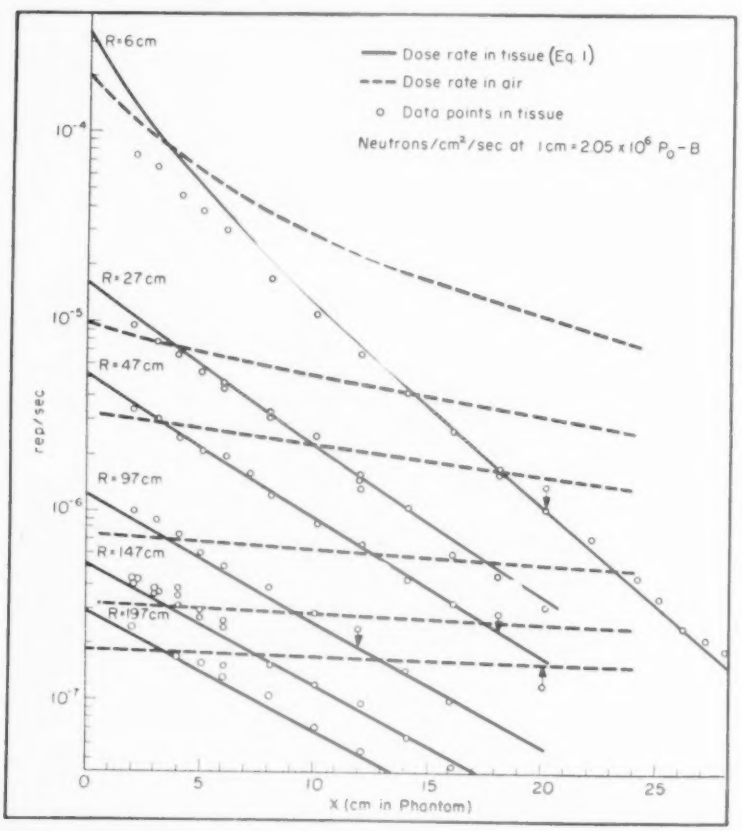

FIG. 4. Results obtained along phantom axis

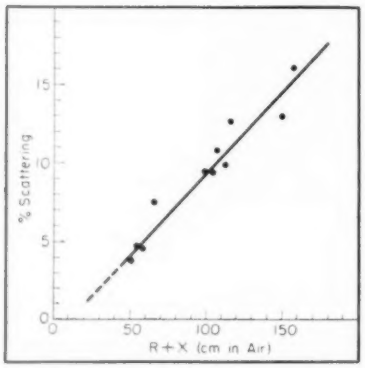

FIG. 5. Floor scattering as a function of $(R + X)$ in air

$$\Sigma_i[\{\ln D_0 B - X_{i/L} - 2 \ln (R - X_i)\} - \ln D_i]^2 = \text{minimum.} \quad (2)$$

From this minimization, L is 7.52 cm and D_0B is 1.13×10^{-2} rep/sec.

The dashed lines represent the air dose for the given values of R and X. A value of D_0 of 7.22×10^{-3} rep/sec was obtained from eleven measured points by the method of "least squares." The data were fitted to a simple inverse-square relation after appropriate corrections for scattering from the floor were made. Figure 5 shows the ratio of dose rate due to scattered radiation to the dose rate in air as a function of the distances between source and detector for the case in which the center line of the phantom is 112 cm above a cement-over-earth floor. No significant part of the dose in the phantom material was due to neutrons that were scattered into the phantom from the floor.

Thus, if we assume that Eq. 1 properly represents the experimental data, we find $D_0B = 1.13 \times 10^{-2}$ rep/sec when D_0 is 7.22 rep/sec and, therefore, $B = 1.56$. The two constants characteristic of the source and phantom are then $L = 7.5$ cm and $B = 1.56$ for relaxation length and buildup factor.

Discussion

The simple exponential form which has been chosen for the depth-dose curves can be justified as an empirical formula only; no theoretical significance need be attached to it. The data points on the curve $R = 6$ cm (Fig. 4) consistently fall below the value of Eq. 1 for values of X from 0 to 8 cm. This may be due to mechanical limitations of the register as mentioned previously. Several of the data points for some of the extremely low dose-rate curves (e.g., $R = 97$ cm and 147 cm) are consistently high; perhaps this is due to electrical disturbances in the commercial power line from which the electronic system drew its energy. If such is the case, the low dose rates would be more sensitive to such disturbances than would the higher dose rates. There is also the possibility that the departure from Eq. 1 is a function of R; in such a case the departure may well represent the difference between the dose rate due to radiation from a point source and the dose rate due to radiation from a broad beam. Although the solid lines (representing Eq. 1) have been extended to values of dose rate at $X = 0$, one is not justified in assuming that Eq. 1 is valid empirically for values of $X \leq 2$ cm.

On examination of the depth-dose curve calculated by Snyder and Neufeld (*1*) (see Fig. 6), one notes that for values of $X > 3$ cm the depth dose falls off exponentially; in fact the relaxation length in this example is 7.51 cm as compared to 7.52 cm in the experimental case. For values of $X \leq 3$ cm, however, there is a marked departure from the exponential form. With the data of Snyder and Neufeld for the calculated first-collision dose of 3.5×10^{-8} rem/n and the total dose of 5.3×10^{-8} rem/n at the phantom surface, the factor B becomes 1.51. (For the purpose of this discussion, 1 rep = 10.5 rem; Snyder and Neufeld used an RBE of 10 for the part of the dose contributed by protons and 20 for the part contributed by heavier atoms.)

W. A. Mills (*7*) has found a value of $B = 1.20$ for a *small* tissue-equivalent phantom. In the calculations of Snyder and Neufeld, the experiments of Mills, and this present experiment the departure from the exponential appears to occur between the phantom surface and a point 1–5 cm inside the phantom. From the information available at present, it would seem that one is justified in using a relaxation length of 7.5 cm and a buildup factor of 1.5 for large tissue-equivalent phantoms and 2.5-Mev neutrons (from either a point source or a broad beam). There is reason to believe (re. W. A. Mills) that the values of both the relaxation length and buildup factor change with phantom size, especially when the phantom is small, i.e., dimensions of the order of several mean free paths or less for the neutrons.

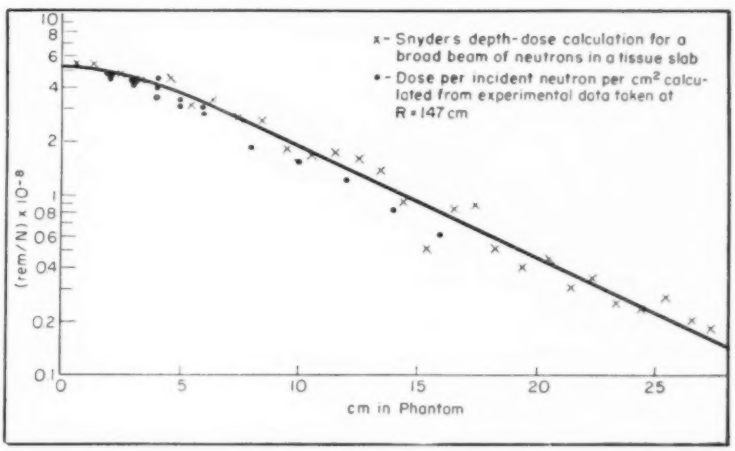

FIG. 6. Depth-dose curve for a broad beam of neutrons with 2.5-Mev average energy

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Fast-Neutron Scattering: A Correction for Dosimetry

Applicable to neutron-dosimeter calibration in air, the inverse square law predicts dose rate for source-to-detector distances of 20–150 cm. Measurements at various heights above concrete agree with albedo-theory curve

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SINCE SCATTERED RADIATION reaching the point of measurement is a major problem in dosimetry, it would be desirable to determine:

1. Variation in neutron dose rate at a point in air with the distance between the source and detector (D)
2. Variation with the height (H) of the source and detector above a concrete slab
3. If the inverse square law predicts the correct dose rate at points in air
4. Whether the scattered neutron dose rate can be accurately measured by introducing a paraffin frustum of appropriate thickness between the source and the point.

The conclusions of this experiment apply directly to calibration of a neutron dosimeter in air by weighting the neutron spectrum reaching the instrument by the first-collision-dose curve.

Experimental Set-Up

The experimental arrangement for measuring neutron scatter from concrete is shown in Fig. 1. The detector (*1*) is an ethylene-polyethylene type proportional counter. A cathode-follower preamplifier drives the counter signal through 60 ft of cable to the linear A-1 amplifier. The A-1 amplifier discriminator is biased to 1 pulse/sec with 2-r/hr gamma radiation incident on the detector. The A-1 linear amplifier drives the pulse integrator (*2*) (a device that automatically adds the pulse heights) and a scale-of-64 scaler. The neutron dose is proportional to the summation of the pulse heights. The source was $Po^{210}B$, which emits neutrons with a mean energy of 2.6 Mev.

The preamplifier and detector were sealed inside a 1-mil polyethylene bag. A small quantity of desiccant ($CaSO_4$) was enclosed in the bag to keep the air dry so that it was possible to perform the experiment out of doors, where undesired scattering material was at a minimum.

Scattering Measurements

Curves showing the neutron scattering from concrete (which varied in thickness from 3 to 4 in.), as a function of the distance above the concrete for several different source-to-detector distances, are shown in Fig. 2. The dose rate has been normalized to unity for the flat portion of each curve. The percentage of neutron scattering increases as the source-to-detector distance increases until D reaches 160 cm, and then a maximum appears in the curves.

Height above concrete. As the source and detector approach the concrete from above, there is a place where the neutrons scattered from the concrete begin to affect the dose rate. As H decreases further, the scattered neutrons reaching the detector increase, causing the rise in the curve. The dose rate reaches a maximum at the point $H/D \cong 0.25$. For lower values of H/D, the neutrons that are scattered have to travel increasingly greater distances through the concrete to reach the detector due to the fact that the neutrons are effectively scattered at some distance below the surface of the concrete. The result is a net decrease in dose rate.

When $H/D < 0.05$, the concrete effectively absorbs the neutrons scattered in the concrete as far as can be detected at the position of the detector. The dose rate when $H/D < 0.05$ could even be less than the flat portion of the curve, because there is 2π air scattering instead of 4π air scattering. The statistical error of each count is shown on these curves.

Paraffin frustum. Figure 3 shows data obtained with a 44-cm paraffin frustum between the source and the

*ORNL is operated for the Atomic Energy Commission by the Carbide and Carbon Chemicals Co.

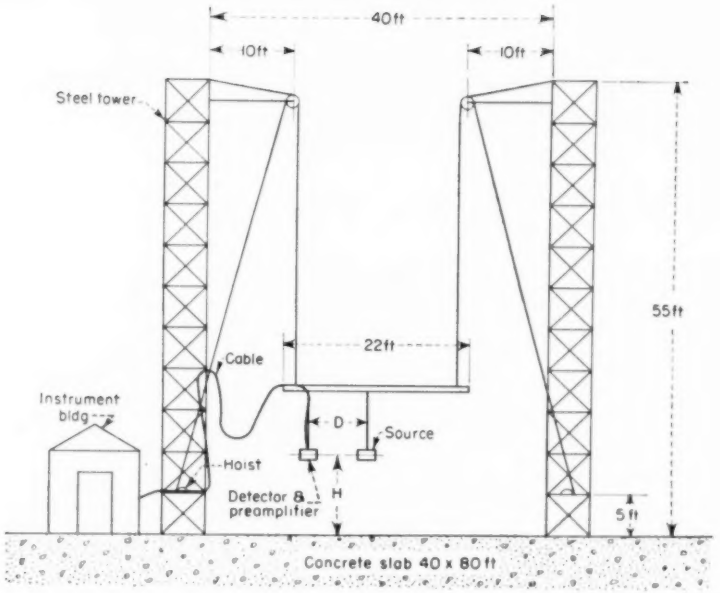

FIG. 1. Experimental arrangement for measuring fast-neutron scattering as function of source height above concrete at various source-to-detector distances

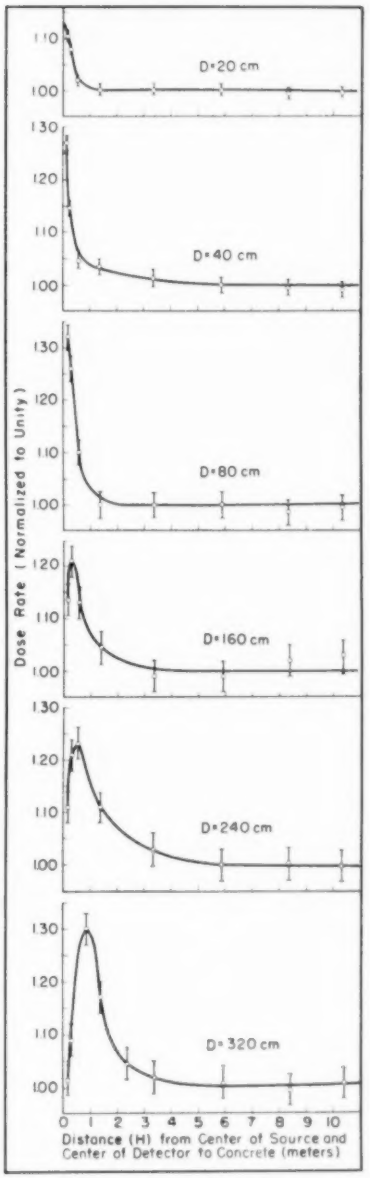

FIG. 2. Dose rate vs *H* (height above concrete) for various values of *D*

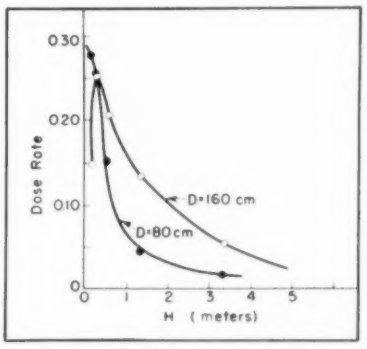

FIG. 3. Paraffin-cone measurements

detector. These curves follow very closely the scattered-neutron component of curves of Fig. 2; therefore, if a paraffin frustum of appropriate dimensions is placed between the source and detector, the dose recorded is due to scattered neutrons only. The statistical error of each curve is 5%.

Source-detector distance. Figure 4 is a plot of the dose rate as read from the flat portions of the curves of Fig. 2 (i.e., for heights above the concrete where neutron scattering from the concrete is negligible) against the corresponding distance between the centers of the source and the detector. The experimental error is shown.

The dose rate follows the inverse square law up to a distance of about 1.5 meters between the source and detector, and then the dose rate seems to increase above that predicted by the inverse square law. It is thought that this increase above the inverse square law is due to air scattering.

Theoretical Scattered Dose

By means of the albedo theory (*3*), a theoretical curve can be formulated that agrees with the experimental curve, within the experimental error. The ground is assumed to reradiate an amount of energy that is proportional to the amount of energy incident upon it. This constant factor of proportionality is here defined as the dose albedo (α), since changes in tissue dose with energy are neglected. The amount and angular distribution of the ground-reradiated dose per unit of incident dose is assumed to be independent of the angle of the incident dose on the ground. Also, the amount of the reradiated dose is assumed to be proportional to the cosine of the angle with respect to the normal to the surface.

Let $E_{\cos}$ = the scattered dose per square centimeter per second reaching the detector, assuming cosine scattering from the concrete, and N_0 = the source energy emitted per second. The meaning of the other quantities is clear from Fig. 5. Combining Plesset's Eqs. 9 and 10 (*4*)

$$E_{\cos} = \frac{\alpha N_0 H^2}{4\pi^2} \left[4 \int_0^{\infty} \frac{\rho d\rho}{(\rho^2 + H^2)^{1/2}[(\rho + D)^2 + H^2]^{3/2}} \cdot \frac{E(K, \pi/2)}{1 - K^2} \right] \quad (1)$$

where

$$K = \left[\frac{4D\rho}{(\rho + D)^2 + H^2} \right]^{1/2} < 1$$

$E\,(K, \pi/2)$ is the complete elliptic inte-

gral of the second kind. This can be converted to

$$E_{\cos} = \frac{\alpha N_0}{8\pi^2 D^2}\left(\frac{D^2}{H^2}\right)\left[8H^4 \int_0^\infty \frac{\rho d\rho}{(\rho^2+H^2)^{1/2}[(\rho+D)^2+H^2]^{1/2}} \cdot \frac{E(K,\pi/2)}{1-K^2}\right] \quad (2)$$

If

$$f(k) = \left[8H^4 \int_0^\infty \frac{\rho d\rho}{(\rho^2+H^2)^{1/2}[(\rho+D)^2+H^2]^{1/2}} \cdot \frac{E(K,\pi/2)}{1-K^2}\right] \quad (3)$$

where $k = D/H$, then

$$\frac{8\pi^2 D^2 E_{\cos}}{\alpha N_0} = k^2 f(k) \quad (4)$$

A graph of this function $f(k)$ plotted against k is shown in Fig. 6.*

$$\text{Ratio of Dose} = \frac{\text{Dose}_{\text{total}}}{\text{Dose}_{\text{direct}}} = \frac{\text{Dose}_{\text{scattered}} + \text{Dose}_{\text{direct}}}{\text{Dose}_{\text{direct}}}$$

$$\text{Ratio of Dose} = \frac{\dfrac{\alpha N_0 k^2 f(k)}{8\pi^2 D^2} + \dfrac{N_0}{4\pi D^2}}{\dfrac{N_0}{4\pi D^2}} = 1 + \frac{\alpha_r}{2\pi} k^2 f(k) \quad (5)$$

If the dose ratio in Eq. 5 is plotted against $H/D = 1/k$ for comparison with the experimental data, then α in Eq. 5 has a value of approximately 0.32, i.e., the reflection coefficient is 32%. As can be noted in Fig. 7, the theoretical curve falls on the experimental curve within the experimental error of 10%.

* * *

The authors wish to express appreciation to R. K. Abele and G. H. Burger for their design and construction of the proportional counters. Much credit is due also to W. A. Mills and P. N. Hensley for their continued contributions to the experiment.

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* This curve was originally given by Plesset (3); however, R. H. Ritchie noticed the curve was in error for large values of k, so Fig. 6 is the curve as corrected by R. H. Ritchie.

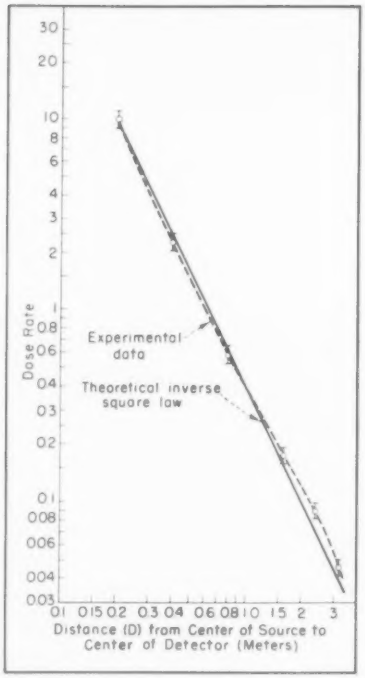

Dose Rate
Experimental data
Theoretical inverse square law
Distance (D) from Center of Source to Center of Detector (Meters)

FIG. 4. Comparison of measured dose with inverse square law

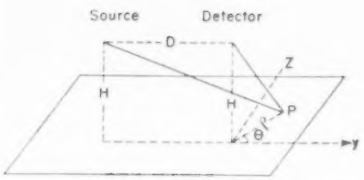


FIG. 5. Geometry used in calculating neutron scatter from concrete

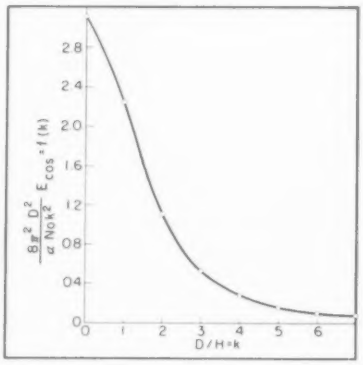


FIG. 6. Plot of function $f(k)$

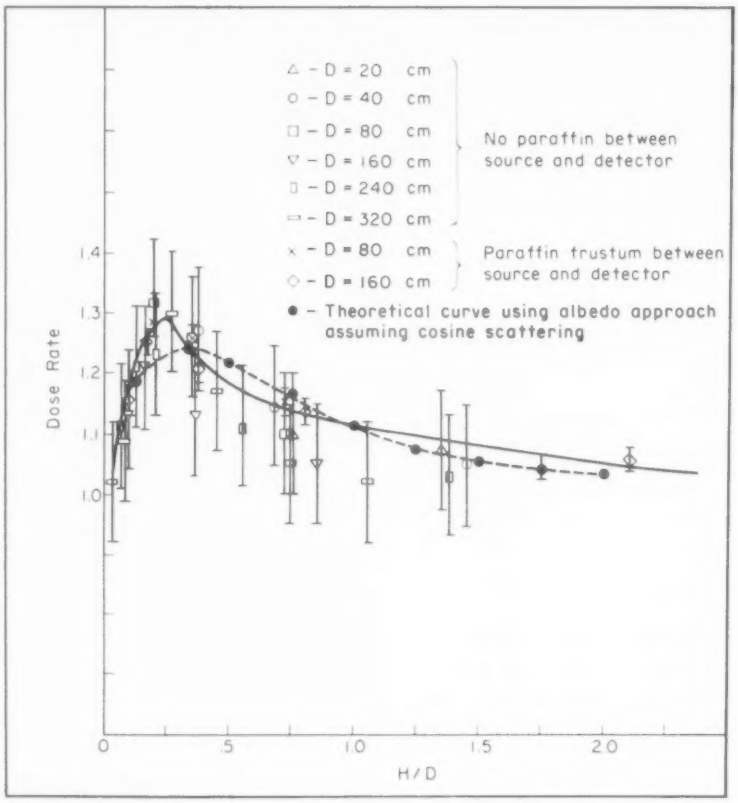
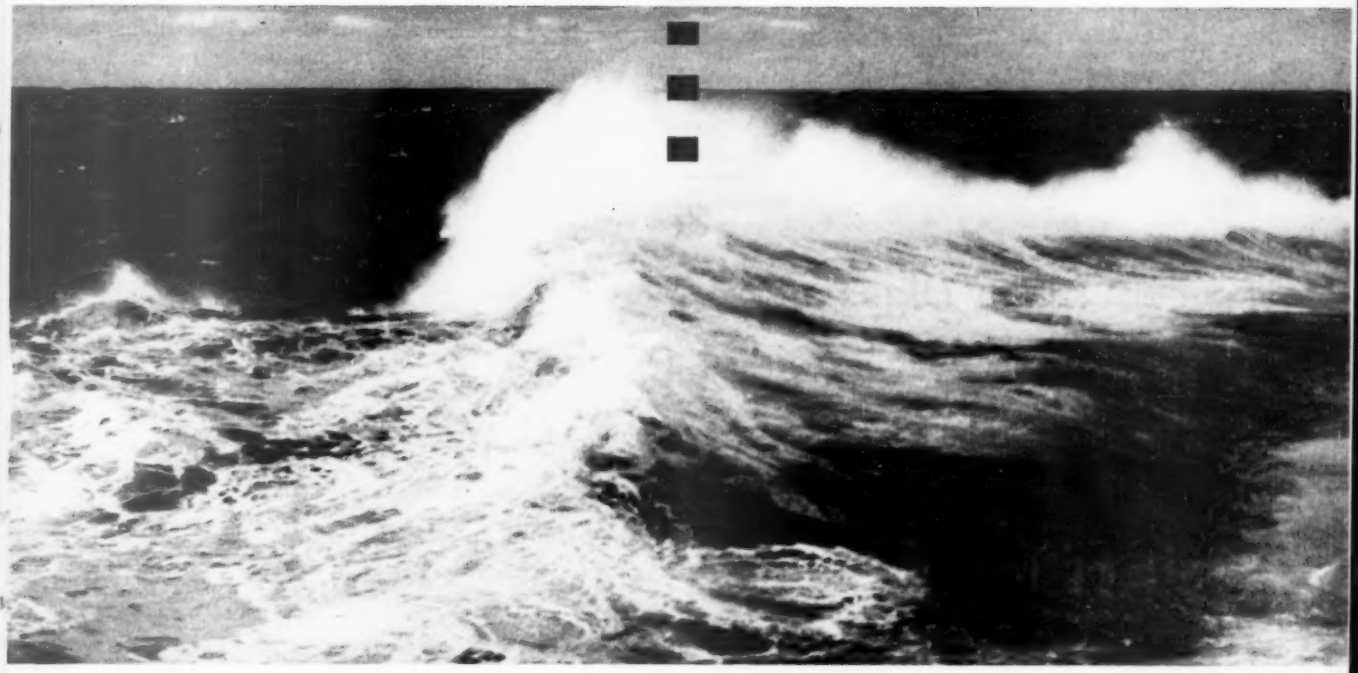

△ - D = 20 cm
○ - D = 40 cm
□ - D = 80 cm
▽ - D = 160 cm
▯ - D = 240 cm
▭ - D = 320 cm
No paraffin between source and detector
× - D = 80 cm
◇ - D = 160 cm
Paraffin frustum between source and detector
● - Theoretical curve using albedo approach assuming cosine scattering
Dose Rate
H/D

FIG. 7. Comparison of experimental results with albedo approximation

TOP SECRET



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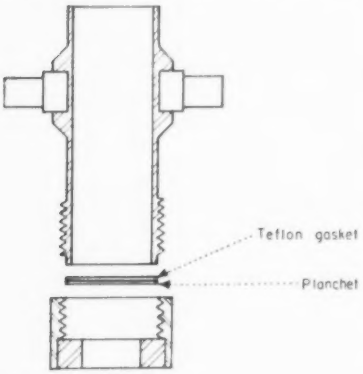

FIG. 1. Centrifuge tube

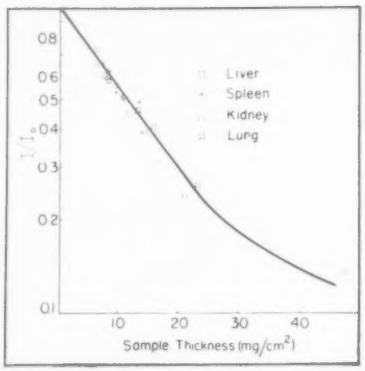

FIG. 2. Self-absorption correction curve for barium sulfate and for digested organs

Procedure for Digestion and Radioassay of Animal Tissues

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Department of Occupational Health
Graduate School of Public Health
University of Pittsburgh
Pittsburgh, Pennsylvania

Wet digestion procedures for radioassaying animal tissues (*1–6*) may be complicated by extraneous material, due either to occlusion of insoluble salts or incomplete digestion, occurring in the final product for assay (*2, 7*). In the method used in this laboratory for assaying sulfur-35 in rat tissues, such material frequently is collected with the barium sulfate precipitate. However, if all the radioisotope could be separated from the suspending medium, then these solids should be of no consequence in the radioactive analysis.

To test this hypothesis, self-absorption measurements made on digested lungs, livers, kidneys and spleens were compared to similar measurements made on barium sulfate. Since the physical characteristics of the digest depend to a large extent on the organ being assayed, any differences due solely to the nature of the material present could thus be detected.

Digestion Procedure

The digestion procedure described here is a synthesis of the various methods in the literature. It may be used with masses of tissue up to 2 gm.

Organs to be digested are placed in standard 6 × ¾ in. test tubes; 2 ml of concentrated nitric acid are added to each. The reaction is allowed to proceed overnight without the addition of heat, thus eliminating the excessive foaming which occurs when heat is applied during the preliminary stages of the reaction. The tubes are then heated in a water bath at 100° C until the digest clears. If foaming occurs, one or two drops of an equal mixture of capryl alcohol and phenyl ether are added. The tubes are cooled and 1 ml of 30% hydrogen peroxide is added. They are again heated in a 100° C water bath until a clear yellow or brown solution results, indicating complete oxidation of the organic matter. The tubes are cooled, and following the addition of 2 ml of concentrated hydrochloric acid to each, are heated in the water bath until the dense brown fumes of nitric acid cease to come off.

The digests are cooled and the *p*H raised to 6–7 by the addition of a saturated solution of sodium hydroxide, using a methyl red-bromthymol blue indicator (*2*). Although the digest is clear during the acidic stage, the addition of the sodium hydroxide causes the reappearance of the suspended solids.

To facilitate the precipitation of all the radioactive sulfate, 6.2 mg of carrier sodium sulfate in 0.87 ml of 0.1*N* Na_2SO_4 solution are added. Barium sulfate is then precipitated by adding an excess amount of barium chloride. This precipitation is carried out at 70° C and *p*H 6–7 for at least 2 hr.

To achieve uniformly thick, reproducible samples for counting, specially constructed stainless-steel centrifuge tubes (Fig. 1) are used for collecting precipitates. Weighed aluminum planchets, previously washed in detergent and dried under an infrared lamp, are mounted on the tubes using Teflon gaskets and Cello-Seal (Fisher Scientific Co., Pittsburgh, Pa.) to insure a tight seal. The sides of the tubes are then wetted by adding 5 ml of 1% gum arabic solution. This prevents the barium sulfate from adhering to the sides of the tubes.

The precipitated digests are quantitatively transferred to the tubes by repeated washing with distilled water and the tubes are centrifuged for 15 min at 2,500 rpm. After decanting, the planchets are removed, dried, and weighed. From the areal thickness thus obtained, the counting rate may be corrected for self-absorption. Assays of the supernatants indicate that the radioactive sulfate is brought down with a high degree of efficiency.

Measurements

The data in these experiments were taken with a 1.7-mg/cm² end-window Geiger tube and a windowless gas-flow counter. Both counters were standardized with a C^{14} β-ray standard. Corrections were made for background, coincidence loss, and window and air absorption. The standard deviation of the counting rate was less than 1%.

Figure 2 presents data obtained from barium sulfate, lung, liver, kidneys, and spleen; I is the sample counting rate and I_∞ the counting rate at zero thickness. The curve for barium sulfate agrees with that reported elsewhere (*8*). The counting rate at zero thickness was obtained by counting a series of increasing sample thicknesses of constant total activity and extrapolating the counting rate-vs-sample thickness curve to zero thickness.

Conclusions

The digestion procedure outlined has been found satisfactory in the analysis

of animal tissues for radioactivity. According to Fig. 2, the suspended solids affect the self-absorption characteristics of the digests from the various organs. The deviations of the tissue data from the barium sulfate curve may be explained by the fact that the deposits on the planchets, although relatively uniform, may contain surface irregularities due to the deposition of one or more large particles. The greatest amount of suspended material is encountered in the liver digestion. Here, fat-like substances (7) are deposited in masses on the planchet, producing the maximum degree of surface irregularities and the greatest deviation from the curve. However, the departures are, in the opinion of the authors, not significant in most biological work.

In making the correction for self-absorption, therefore, the correction factor for the corresponding density thickness of barium sulfate may be applied to the digests of any organ.

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Potting Photomultiplier Tubes

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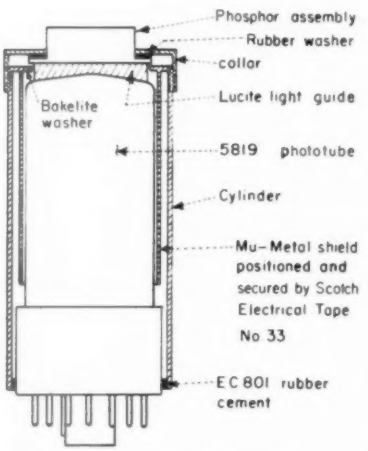
This photomultiplier-tube potting technique involves adhering a Lucite light guide to the tube's cathode surface, surrounding the tube with a Mu-Metal shield, and enveloping the whole in an aluminum "can."

The light guide provides a flat contact surface with the crystal scintillator for the RCA-5819 tube and serves as an insulator for the 5819 and DuMont-6292 against cathode-surface current leakage. The shield prevents magnetic-field interference with the cathode-to-first dynode electron flow. The whole is made light tight by the aluminum can.

* Operated by The University of Chicago under contract W-31-109-eng-38.



ASSEMBLED potted photomultiplier

Preparations for Cementing

The lower $\frac{1}{4}$ in. of the tube base is roughened all the way around by rubbing gently with emery cloth. Similarly, the inside of the aluminum cylinder is roughened for about 1 in. at that end to which the tube base is to be attached. This roughening improves the adhesion of the cement to both tube base and aluminum cylinder and increases the joint strength.

Guide and Tube Assembly

Insert the tube in a base. A 5819 tube socket serves excellently. Clean the cathode (upper) surface of the tube thoroughly with acetone. Place the tube in an upright position in an oven held at approximately 70° C. On the cathode surface place a small piece (about a $\frac{3}{8}$-in. cube) of clean, clear polyvinylacetate. Supply a slight excess to assure successful completion of the step; the excess is easy to remove.

Support a half of a Petrie dish above the polyvinylacetate and tube to prevent dust accumulation on them.

While waiting for the polyvinylacetate to become sufficiently pliable, clean the light guide with ethyl alcohol, dry it with Kleenex to remove any cloudiness, and place it in the oven alongside the tube. Ten minutes heating of the guide should warm it sufficiently to secure good adhesion of the parts by the polyvinylacetate.

When the polyvinylacetate is melted and the light guide is warm enough, remove the parts from the oven, blow off (with the breath) any dust accumu-

List of Materials

Aluminum cylinder—$2\frac{15}{32}$-in. diameter, $4\frac{7}{8}$ in. long, $\frac{1}{16}$ in. thick
Aluminum collar—threaded
Brass ring—threaded
Mu-Metal shield—0.025 in. gage, Allegheny hydrogen-annealed, $2\frac{1}{16}$ in. inside diameter × $3\frac{1}{4}$ in. long. Made by Allegheny Ludlum Steel Corp.
Photomultiplier tube—RCA-5819 or DuMont-6292
Tube base—RCA-5819 tube socket
Lucite lightguide—$\frac{1}{8}$ in. thick × $1\frac{5}{8}$-in. diameter for DuMont tube; $\frac{1}{4}$ in. thick × $1\frac{3}{4}$-in. diameter for RCA tube
Polyvinylacetate—"Vinylite Plastic, AYAC Blend 3695"; obtainable from The Bakelite Company (Box N, South Charleston 3, W. Va.; order number is BVS-3900); this must be clear, white, soft enough to be workable at temperature not detrimental to phototube
Rubber cement—Minnesota Mining and Manufacturing Co. (Detroit, Mich.); base agent, EC-801, and hardener, EC-807: mix 4 parts base with 1 part hardener shortly before use; keep base agent under refrigeration when stored
Scotch Electrical Tape No. 33
Gasket—sponge rubber
Ring—Bakelite; inside diameter depends upon outside diameter of light guide
Masking tape
Tygon paint—white plastic, U. S. Stoneware Co. (Akron, Ohio)
Polystyrene sheet—thin
Colloidal silver paint

lated on the light guide and place the guide on the tube. With a small piece of plate glass, apply gentle pressure to the light guide and gradually work the excess of polyvinylacetate from between the guide and the tube. Plate glass permits uniform distribution of the pressure and avoids distortion that may result by direct use of the fingers. Distortion results in a nonuniform layer of wetting agent between crystal and light-guide surface and allows this wetting agent to flow out more readily when tube is used in horizontal position.

If need be, the parts may be returned to the oven to be rewarmed before completing the assembly.

While the polyvinylacetate is still soft, peel away, with the fingers, as much as possible of the excess which has been squeezed from the joint. Center light guide on the tube.

Let the assembly cool. When the polyvinylacetate has hardened, wipe away the remaining excess of polyvinylacetate, using Kleenex wetted with ethyl alcohol. Do not use acetone for this purpose, as it will attack Lucite.

The top surface of the light guide should now be covered with masking tape and this covering should be retained in place until the "potting" is completed, thereby protecting the guide from marring and solvents.

To prevent loss of light through the edge of the light guide, the edge is painted with three coats of "Tygon" white plastic paint. Approximately 1 hr should be allowed between successive applications of the paint. Ease of application and tenacious adherence to the Lucite make Tygon paint desirable. But improved reflecting power is desirable. Tygon paint is soluble in acetone; therefore, for any cleaning operation, use ethyl alcohol.

Current Leakage

Although the light guide acts as an insulator against current leakage, another preventative is provided by painting a ring of colloidal silver about the base of the light guide. A strip is then painted from this ring down the side of the tube to pin 14, the cathode. (Be sure that the surface is well cleaned with ethyl alcohol before this painting.)

Use a thin sheet of polystyrene, held in place with Scotch Electrical Tape No. 33, to cover the silver paint strip running down the side of the tube base, to insulate it from the aluminum can that is to be cemented to the base. The tape should be placed so that most of the circumference of the lower portion of the tube base can be contacted with the rubber cement.

Mu-Metal Shield

To prevent interference of magnetic fields with the flow of electrons from the cathode surface to the first dynode of the photomultiplier, a Mu-Metal shield is placed about the tube. Electrical Tape No. 33 is wrapped around the envelope of the tube about $\frac{3}{4}$ in. above the base and also approximately the same distance below the top of the tube, so that the Mu-Metal shield can be positioned properly. This is done by sliding the Mu-Metal shield over the tape and then slipping 2 of the Bakelite rings (such as used in potting) over the Lucite light guide. The Mu-Metal shield is then so positioned that, with the lower one of the Bakelite rings resting on the upper edge of the Mu-Metal shield, the top surface of the upper ring is flush with the upper surface of the light guide. Electrical tape, wrapped around the lower edge of the shield, fixes it in position.

Assembly before Potting

The assembly consists of an aluminum cylinder, the upper end of which is fastened to a threaded brass ring, a Bakelite ring to center the tube within the cylinder and thus to "float" the tube within the confines of the cylinder, and a threaded aluminum collar that positions the crystal relative to the tube, retains this crystal, and, with the help of a sponge rubber gasket, completes the light-tightness of the assembly.

Note that the inside diameter of the Bakelite ring is proportioned to the outside diameter of the light guide, being larger for the RCA-5819 than for the DuMont-6292. This is the only difference in the potting parts required for these tubes.

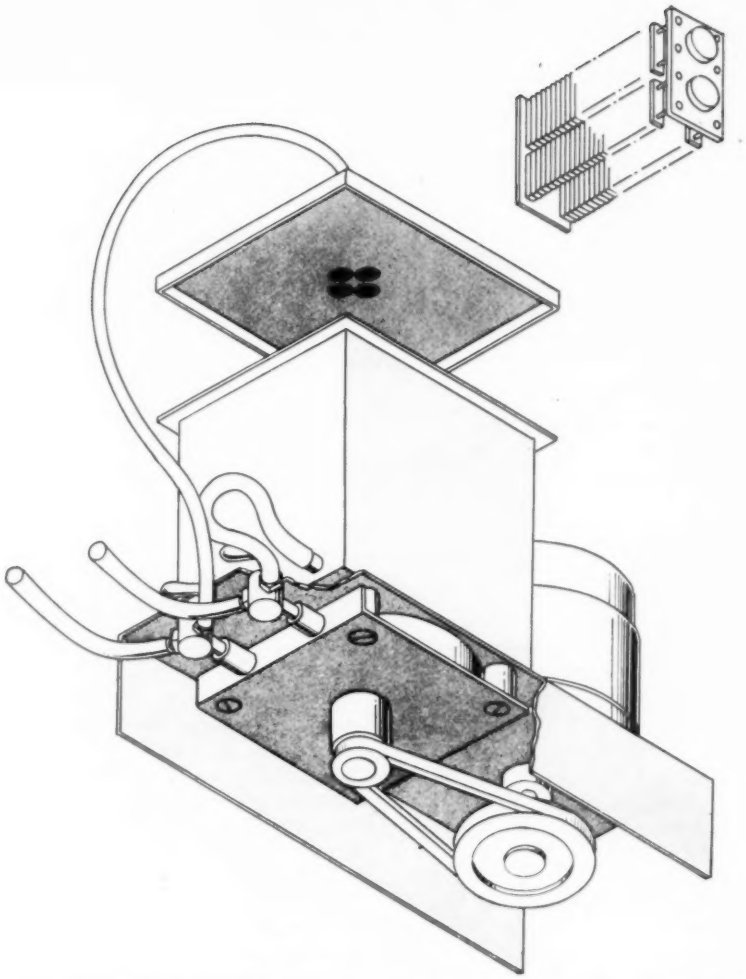
Potting the Tube

The upper end of the aluminum cylinder is turned down on the outer side and a brass ring, threaded on its outer side, is secured at this place, the brass ring projecting slightly beyond the aluminum cylinder. The small recess, formed by the projection of the brass ring beyond the aluminum cylinder, is filled with rubber cement. Into this cement-filled recess a Bakelite ring is set. Separately spread a thin film of the rubber cement around the wall of the upper half of the light guide, which has already been attached to the phototube Then insert the light guide and tube through the lower end of the aluminum cylinder until the light guide protrudes through the center of the Bakelite ring. Now take a second Bakelite ring of the same size, slip over the light guide, turn the entire assembly upside down, and place it onto a flat surface. The second ring assures that the light guide will protrude above the first Bakelite ring, simplifying the removal of crystals from the light-guide surface. During this operation the tube is held as rigidly as possible with one hand to prevent the first Bakelite ring from being forced out of the recess. The other hand places the second Bakelite ring and guides the opposite end of the assembly until it has been placed in the desired position with the light guide end of the tube on the flat surface.

The tube base is now centered in the aluminum cylinder and braced in this position with pieces of cork or of electrical tape. Then the opening is filled with rubber cement, forcing it in with a spatula, a depth of $\frac{1}{4}$ in. being sufficient. A greater depth is not advisable since the other parts of the assembly can be reused if the tube has to be replaced. The rubber cement will harden overnight. The process can be accelerated by adding more hardener to the base agent, but experience has proven that too much hardener decreases the adhering properties. The excess can be trimmed away with a razor blade. Any that remains can be removed with Kleenex wetted with ethyl alcohol. Acetone can be used only with extreme caution near the light guide, since the acetone will destroy its surface. It is essential that all surfaces to which cement is applied be free of dirt and grease.

Safety goggles should be worn at any stage of the process when pressure is applied to the tube, since breaking a tube might result in injury from flyingglass.

Photomultipliers potted by this procedure have been used successfully at this laboratory for several years. Their use outside the laboratory is limited by the failure of the polyvinylacetate cement to remain sufficiently fluid below about 40° F. This may result in a loss of optical contact between the light guide and photomultiplier if the assembly is used or stored for long periods below 40° F. Attempts to find an adhesive that would remain plastic at low temperatures have been unsuccessful.



BATCH-PROCESS UNIT: gallon tank, pump, and one film holder for processing 400 films

Simplified Film Processing for Radiation Dosimetry

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At the present time, very few film-dosimetry services are operated with as few as 100 users; only relatively few places using ionizing radiation operate their own film system. Several factors have contributed to making film dosimetry difficult and expensive and thus something not to be undertaken as a small operation. These are:

1. Film response in optical density is typically calibrated in roentgens. Due to variation in spectral sensitivity of the emulsion, it is necessary to calibrate the film at each energy level. Since normal use includes diagnostic X-ray and γ-radiation, at least three "R" chambers are required to standardize for X-rays, and a calibrated radium or Co^{60} source of at least 100 mc for gamma calibration.

2. If the films are developed under conventional X-ray conditions, errors arising from differences in time, temperature, condition of the developer, and speed of the film can only be minimized by including a calibration series and constructing a curve from it.

3. Optical density is usually measured with a densitometer. This fairly expensive (about $200) piece of equipment would usually have no other use than for film dosimetry. Thus whether to operate a film service is a problem of economics and convenience.

Calibration

Considering a given film and developer, the conditions of development within normal limits can have only the effects of changing the density produced by a given exposure and the density difference of any two exposures.

In a plot of exposure against density (the calibration curve for film dosimetry), these two changes can be resolved by horizontal translation and change of the slope of the curve, while the shape of the curve is unchanged. By careful processing with selected film and developer, the results are uniform enough to require complete calibration only when beginning.

At the University of California, three known exposure values, producing densities of 0.02, 0.2, and 1.5 (density 3.0 is the maximum for the densitometer used), have proven sufficient to establish the position of the curve. These values are obtained by exposure for one week on a rack having fixed distances from a radium button.

Any changes from the normal in developmental conditions or film speed may be corrected by displacing the "standard" curve so that it passes through these three points. Using this technique, a small user does not have to be able to calibrate his own process but can work from a standard curve

Development

Film-badge development is usually done with equipment designed for dental X-ray work, since the film sizes are the same. This equipment functions smoothly for dental work, but this system, designed for quick inspection during processing and a steady work load, seems to impose an unnecessary burden on the inherent accuracy of processing. Another system of handling based on the amateur photographic light-tight tank is much easier to use and produces more uniform results. The table (p. 44) compares the two systems.

Agitation. Agitation is often neglected. Development of an exposed film area depends on replacing exhausted developer in the emulsion. In a still tank, there is some interchange of

Process Comparator for Factors Influencing Development

	Batch Process	*Group Process*
Developer	Small amount, 400 films/gal	5–15 gal
Changes in developer (exhaustion, oxidation, metallic ion loading)	Use fresh for each batch of film	Large quantity makes complete change expensive. Calculation for replenishment based on number of film run, time standing, temperature, air added
Time	± 5% absolute, errors compensated in reading	Careful attention required for protracted period
Temperature	Requires only bringing solutions, sometimes tank, to correct temperature. Temperature change < 1° F in 5 min	Thermostatic control required, possibly refrigeration if cold water supply goes over 70°
Agitation	Simple circulation required due to close film spacing	Usually none, up to 10% density variation top to bottom possible

developer from the solution into the film. The exhaustion products tend to flow down the film. According to C. E. K. Mees,* a variation in density of as much as 10% from the top to the bottom of a film may result.

The effect of the rate of agitation turns out to be the conventional one of eliminating the boundary layer of liquid formed on a solid surface in laminar flow. Effective agitation for reproducibility of results is then in the turbulent-flow region. Some recent work by Morgan and Van Allen† indicates that development is constant for rates of flow over the film above 1.5 in./sec. For their system of reciprocating paddles traveling close to the film, the upper limit of this straight-line portion of the agitation-development effect was 4.5 in./sec. This upper limit is no doubt dependent on the method of agitation used.

Batch Process

Batch processing equipment represents the minimum investment and leads to the shortest working time for a work load between ten and at least a thousand films per exposure period. For small-scale operation (up to a hundred films), a light-tight tank with a pouring trap is suitable. This can be designed to use one pint of solution for each fifty films. A brief description of batch processing will show some of the resulting simplifications.

After collection, the films are usually identified by numbering them. This is conventionally done by perforating with a modified checkwriter or exposing to X-rays through suitable perforated filters. Identification can also be done by scratching the emulsion or by a notching code.

In a darkroom lit with a paper safelight (Wratten OA), the films are removed from their packets and loaded into holders. The loaded holders are then placed in a small tank with a light-tight cover. Regular illumination may be used after this so that the darkroom need consist only of a closet with three feet of bench top. Fresh solutions of the developer and fixer are stabilized at the correct temperature, usually by immersion in a sink full of water. This can be started before the loading. If the tap water is not cold enough, some ice in the water batch will bring the temperature down. If the tank is ten degrees above or below the developing temperature, it should also be brought to approximately the correct temperature. Since each part of the process lasts only five minutes, the temperature change is very minor. The successive solutions are poured into the tank through a light trap and the tank is agitated by shaking. Washing is accomplished by placing the tank with the cover removed under a tap and allowing the water to overflow. Drying (with the films left in the holders to prevent curl) may be done in any conventional manner.

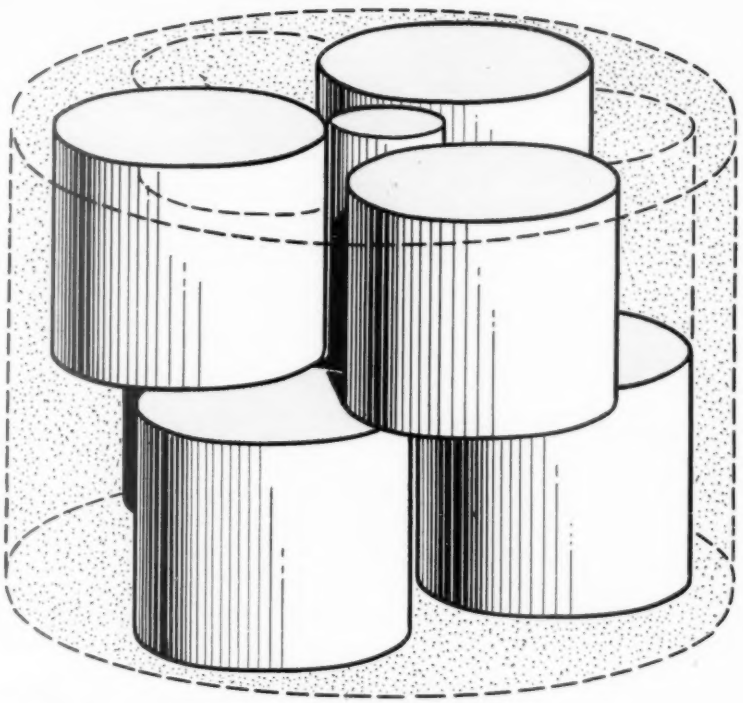
If the scope of the operation will not support investment in a densitometer, a calibrated density wedge built into a viewing box with an evenly diffused light source behind the wedge may be used. The density of a zero-exposure film must be subtracted from the reading obtained for any film before entering the chart to find the exposure. Conventionally, a densitometer is zeroed with this unexposed film in the measuring position. An average person with a small amount of practice can match densities closer than ±10%, provided the density values are between 0.1 and 1.5. With a wedge comparator with a film combination of Eastman Kodak Type K and Periapical Regular in a holder with a 1-mm cadmium filter (AEC specification PF1B), diagnostic X-ray may be evaluated from 5 mr to 8 r and gamma radiation from 25 mr to 3 r. Values on either side of these, particularly at lower levels, may be estimated with fair accuracy. With a densitometer that reads densities between 0.01 and 3.0, this same combination of films evaluates 1 mr to 20 r of X-ray or 2 mr to 3.5 r of gamma radiation. Other films may be used to extend the upper limit to any desired value.

If standard specifications were accepted for film, developer, and processing conditions, standard calibration curves could be published. With these curves, simple batch processing equipment, and a comparison wedge, accuracy may be maintained. The cost per film with 25 or more films processed with this minimal equipment should not be greater than the price charged by an outside agency.

In the developing tank illustrated, up to 400 films may be processed in one gallon of solution. With a tank of this size, hand agitation is too difficult and too apt to splash out developer. Also, the time required to pour in and out of a light trap becomes an appreciable fraction of the total development time; as a consequence, the films at the bottom of the tank would be developed more than those at the top. These two difficulties can be overcome by using a circulating pump to obtain a fluid flow of 1½ in./sec past the film. Three-way stopcocks in the intake and outlet sides of the pump allow the operator to pump the solutions from bottles into the tank at the agitation rate that fills the tank in 10 sec or less. Removal is done in the same manner and the solutions put back in the bottles. Washing should be started by pumping in a fill of water and pumping it out after a short circulation period. This flushes the pump and the lines.

* C. E. K. Mees, "The Theory of The Photographic Process" (Macmillan Co., New York, 1942).

† Morgan, Van Allen. The sensitometry of roentgenographic films and screens. *Radiology* **52**, 832 (1949).



CLOVERLEAF source consists of seven Co^{60} cylinders

Available Co^{60} Source for Teletherapy

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A double-overlapping-cloverleaf source was designed to make maximum use of the cobalt-60 currently in plentiful supply from one of the Oak Ridge facilities. This source material is now available as 1-cm-diameter and 0.32-cm-diameter rods in lengths up to 4 cm and with specific activities ranging from 7 to 11 curies/gm.

For teletherapy use, when sources in the multihectocurie range are used, it is an advantage to have a short source-to-skin distance (SSD) available. This restricts the maximum allowable diameter of the source, arbitrarily chosen as 2 cm. With this diameter, approximately 30-cm collimation distance gives penumbra relationships similar to those of the larger machines. The double-overlapping cloverleaf (see illustration above) was chosen as an optimum compromise of economy, curiage, penumbra, and available materials.

Source Construction

The cloverleaf source consists of seven pieces of Co^{60}: six pieces are 1-cm diameter by 1-cm length, and one is 0.32-cm diameter by 1.27-cm length. The small piece is used as a central core and the larger pieces are grouped around this core in two layers. The top layer is in a cloverleaf pattern with three 1-cm rods arranged at 120-deg angles around the core. The bottom layer is similar but is 60 deg out of phase. Thus the total surface presented to the patient contains Co^{60} in three different depths. The depth of 6.3% of the area, the central core, is 1.27 cm. The depth of 67.5% is 1 cm, but half of this area is at 1-cm greater SSD; the depth of 26.2% is 2 cm. The maximum diameter of the source is 2.3 cm; the minimum is 1.9 cm.

The source capsule for the cloverleaf design has been drilled to fit; there is thus the possibility of maximum shielding in all except the forward direction where there is no unnecessary shielding. A jig has been made to allow for simple loading. The cloverleaf fits into the standard source capsule (*1*).

Source Strength

The characteristics of the first such source to be made can be used as an example of the advantages and disadvantages of the design (Table 1).

The calculated roentgens per hour at 1 meter (rhm) is about 476 rhm or 7.9 r/min at 1 meter (rmm). The actual measurement was 381 rhm or 6.35 rmm. A number of corrections partially explain the discrepancies. There was approximately 4% absorption in the steel cap of a prototype source capsule; our measurement of the output was made about two months after the measurements of the individual pieces. The calculated value was reduced to 7.4 rmm.

The remaining discrepancy is probably due to the way in which the individual pieces were measured to give us the original "paid-for-value" of 452 curies.† These measurements, made by ORNL for determining the price of

*Work was performed under contract with the U. S. Atomic Energy Commission.

†Since this article was written, ORNL has adopted a new method of measuring Co^{60} that allows closer approximation of calculated and measured values.

TABLE 1—First Source Made

	1-cm rod	*⅛-in. rod*
Diameter (cm)	1.0	0.3175
Length (cm)	1.0	1.27
Presenting-face area (cm^2)	0.7854	0.1008
Volume (cm^3)	0.7854	0.1280
Weight (gm, $d = 8.9$)	6.99	1.14
Total weight of source (gm)	43.08	
Total curiage (ORNL)	452	
Average specific activity (c/gm)	10.5	
Average curiage per piece (curies)	73.35	12.0

the cobalt, are made in a lead chamber with 1-in.-Pb attenuation between source and detector in a very broad-beam geometry. Although the instruments are calibrated accurately, they are calibrated to measure total curies; the confidence level is not better than 20%. The detector "sees" an aspect of each individual piece of cobalt that might be different from that used in a teletherapy machine. In measuring the output of the source in the teletherapy machine, we measure only a small fraction of the 4π geometry in air even with the largest cone in the teletherapy unit, and little of the scatter build-up is included. It appears that, of all these possibilities for discrepancy, the use of a wide-beam geometry in the calculation of curiage will give a constant bias; therefore the statement of curiage on the shipping ticket will be about 10% higher than if it were measured under the conditions of teletherapy use.

Cost

The cost of Co^{60} for the cloverleaf source, adjusted to match the data in Table 2, was \$2,750 or \$7.20/rmm on delivery. It is not the most economical source nor is it the most economical design.

It is interesting to calculate the probable cost of what might be designed as a best possible source (*2*) when the same or even better production facilities are used, such as given in Table 2. The 1.5-cm-diameter source is in the cost range comparable to the lower specific activity and appears to be an excellent source size. Since the hectocurie Co^{60} machine is designed for a maximum of 600 rhm, Table 2 shows the cost relationships at maximum output.

Since the facilities for high-specific-activity production are limited, all of their production should be saved for higher-curiage machines. Further, the problems of handling the higher-curie sources increase almost exponentially with increasing curiage. Costs in addition to those of the source shield must be taken into account. Until a few years ago, there were no facilities for handling high-curiage sources; even today handling experience is limited.

The 10-curies/gm material is produced in an AEC facility that produces neutrons for various purposes not related to teletherapy. This low-specific-activity Co^{60} need not be on a strict priority allocation. There can always be a guaranteed production, and it is believed that material can be exported without danger of affecting the American neutron economy.

The cloverleaf design has only one advantage to recommend it—and this advantage takes ultimate precedence over all other factors at the present time and probably for some time to come—it uses Co^{60} that is available now.

TABLE 2—Cost of Cobalt-60 Sources*

Diameter (cm)	*Length (cm)*	*Specific activity (c/gm)*	*Curies*	*Total cost*	*Cost/rhm*
		6.3-rmm source			
2.0	1.4	10	370	\$2,500	\$6.50
2.0	0.25	50	310	\$2,900	\$7.60
1.5	0.4	50	320	\$3,000	\$7.80
1.0	1.0	50	340	\$3,140	\$8.25
		10-rmm source			
2.0	2.85	10	780	\$4,550	\$7.60
2.0	0.37	50	485	\$4,250	\$7.10
1.5	0.65	50	515	\$4,400	\$7.30
1.0	2.00	50	680	\$5,700	\$9.50
Canadian quotation (unknown sizes)		?	500	\$8,800	reirradiation allowance
		30-rmm source			
2.0	impossible	10			
2.0	1.23	50	1,650	\$13,250	\$7.40
1.5	3.25	50	2,550	\$20,000	\$11.00
1.0	impossible	50			
Canadian quotation (unknown sizes)					
3 cm?	3 cm max.?	?	1,800	\$23,220	reirradiation allowance

* Cost includes cobalt-60, capsule, loading, handling, and shipment to New York City.

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Gamma Counting Efficiency of Two Well-Type NaI Crystals

By R. BASKIN, H. L. DEMOREST, and S. SANDHAUS

Radioisotope Unit, Veterans Administration Hospital, Minneapolis, Minnesota

Good efficiency in the detection of gamma rays from liquid radioactive samples has been achieved by the use of well-shaped scintillation crystals. As originally reported by Anger,* the counter made use of a well formed by anthracene crystals. Most counters of this type now use a sodium iodide (thallium activated) crystal $1\frac{3}{4}$ in. in diameter by 2 in. thick with a hole $\frac{3}{4}$ in. in diameter by $1\frac{1}{2}$ in. deep. Such crystals are now commercially available hermetically sealed in aluminum containers. In this form, the crystal holds standard 4-cm^3 glass sample vials; a thin plastic liner protects the crystal against contamination

With the low activities present in medical and biological tracer work, we have encountered situations where 4-cm^3 samples do not furnish sufficient total activity for reliable measurements in a reasonable length of time. In many such instances more than 4 cm^3 of sample is readily available. Such samples can often be concentrated by evaporation, but this involves an extra preparatory step and may result in some loss of the radioactivity to be measured. It was thought desirable, therefore, to construct a well-shaped scintillation counter that would hold

* H. O. Anger. Scintillation counters for the measurement of radioactive samples, UCRL-886 (1950).

a larger sample. With a greater total amount of activity such a counter should give a reduction in the counting time required for a given accuracy even though its efficiency might be less than that of the smaller well crystal.

In selecting the crystal size and the well dimensions, a number of limitations must be considered. The efficiency of the NaI crystal as a radiation detector is dependent upon the volume of crystal available to absorb the gamma radiation. The extent to which the over-all size of the crystal can be increased is limited for practical purposes by the size that can be efficiently coupled to available photomultiplier tubes and by the greater cost of larger crystals. We selected as a desirable size a crystal 2 in. in diameter by 2 in. thick with a hole $1\frac{3}{8}$ in. in diameter by $1\frac{5}{8}$ in. deep. In the sealed unit furnished by The Harshaw Chemical Company, a crystal of these dimensions holds a 20-cm^3 vial and a plastic protective liner. A scintillation counter incorporating this large well crystal was built in our laboratory. This article will report the results obtained with such a counter and the relative efficiencies of the large well counter (20 cm^3) and a small well counter (4 cm^3) for a number of isotopes.

Counting Systems. Two separate counters were used for the two crystals, although the construction was similar for both. The circuit that supplied suitable voltage to the dynodes of the RCA 5819 photomultiplier tubes was of conventional design. A thin Lucite disk was machined to provide a close fit between the crystal and the face of the photomultiplier. Optical coupling at the interfaces was obtained by the use of Aroclor.* The output pulse of the photomultiplier was fed into a cathode follower, amplified, and then recorded on a scaler. The counter assembly was enclosed in a lead shield made up of interlocking rings, which provided $1\frac{1}{2}$ in. of shielding in all directions. Typical background counting rates were 400 cpm for the large well counter and 300 cpm for the small well counter. These backgrounds were reduced to 230 and 190, respectively, by the addition of 2 in. of shielding directly surrounding the crystal.

The counters gave good plateau characteristics, and the operating voltage was selected to be at the center of the plateau for each isotope used. In all cases this voltage was at least 4.5

* Monsanto Chemical Co., St. Louis 4, Mo.

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602		30, 100, 300, 1000
608		.3, 1, 3, 10 (4/hr)
613		.03, .1, .3, 1
603	400 to 2000	1500, 5000, 15000, 50000
605		0.3, 1, 3, 10
606		3, 10, 30, 100
607		30, 100, 300, 1000
604	20-50	30, 100, 300, 1000
610	I^{131} Au^{198}	1, 3, 10 mc I^{131}
609	—	3, 10, 30, 100

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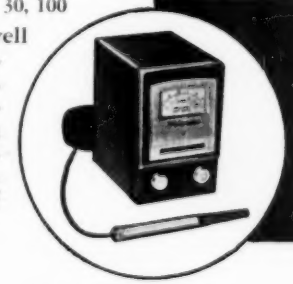

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TABLE 1—Counter Efficiencies for I^{131}

Sample volume (cm^3)	Efficiency (%)		Large well gain factor G
	Small well	Large well	
1	43.6	36.8	0.84
2	43.2	36.1	0.84
3	40.5	35.7	0.88
4	38.8	35.7	0.92
5	36.2	35.0	0.97
6	32.3	35.0	1.08
7	28.8	35.0	1.22
8	25.3	33.9	1.34
10		33.1	1.64
15		28.7	2.13
20		25.4	2.51
25		21.7	2.68
30		19.1	2.83
35		16.9	2.92

TABLE 2—Counting Efficiency of Well-Type Counters for Various Isotopes

Isotope	Gamma ray energies (Mev) and frequency	Efficiency (%)		Minimum detectable activity ($\mu c \times 10^{-3}$)	
		Small well	Large well	Small well (4 cm^3)	Large well (20 cm^3)
Sodium-22	1.28 (100%) 0.5 Ann. 100%	62.7	39.7	0.018	0.006
Chromium-51	0.32 (~10%)	4.3	2.5	0.263	0.090
Iron-59	1.3 (50%) 1.1 (50%)	22.2	11.6	0.051	0.019
Cobalt-60	1.17 (100%) 1.33 (100%)	38.6	22.6	0.029	0.010
Iodine-131	0.364 (~85%) 0.638 (~15%)	38.8	25.4	0.029	0.009
Gold-198	0.411 (100%)	39.8	22.1	0.028	0.010

volts per photomultiplier stage below the point where tube noise became appreciable. The efficiency of these counters was greater at higher voltages, but the increase in background was undesirable in the counting of low activities.

Effect of sample volume. The efficiency of the two counters as a function of sample volume was determined using a solution of iodine-131 prepared from a National Bureau of Standards reference source. The values reported in Table 1 are for absolute efficiency (counts per disintegration). Although the sample wells hold only 4 cm^3 or 20 cm^3, the efficiency for larger volumes was obtained with tall sample vials that protruded from the well in the crystal. The error in these efficiency determinations did not exceed ±5%.

This series of measurements was also done using Fe^{59}. The variation of efficiency with sample volume for Fe^{59} agreed with that for I^{131} to within ±2%.

As is to be expected, the efficiency of the large well counter is less than that of the small well counter for any given sample volume. However, for samples of any given specific activity, the large well counter gives an increase in counting rate with larger volumes. This can be seen by calculating a gain factor, G, defined as

$$G = \frac{\text{Efficiency} \times \text{volume (large well counter)}}{\text{Efficiency} \times \text{volume (small well counter)}}$$

This gain factor is given in Table 1. For volumes greater than 8 cm^3, the efficiency × 8-cm^3 volume is used in the denominator of the equation. It is apparent from the variation in the gain factor that, for volumes greater than 5 cm^3, the large well counter gives an improvement in counting rates; for smaller volumes there is little difference between the two counters. Inasmuch as the cost of the large well crystal is only slightly more than that for the small well crystal, it would seem that the former is to be preferred if a choice is to be made.

It is worth noting that the use of the small well crystal can be extended to larger volumes by the use of a specially designed sample vial that fits into the well and has an upper section shaped like a beaker that covers the cross section of the crystal. This idea can be extended even further to the use of a container that fits into, on, and around the well crystal. Such containers have been tried and, although there is some gain, it is less than that achieved with the large well crystal. Furthermore, these specially fabricated beakers are cumbersome to use and expensive. Where many samples are to be counted, the use of inexpensive standard vials that can be securely sealed is essential.*

As the efficiency of gamma scintillation counters is dependent upon the gamma energy, a series of comparisons of the two well counters was made using different radioisotopes. The specific activity of some of these was not known as accurately as for the I^{131}. However, in no case was the error in the assay of the radioactive material greater than ±10%. With the exception of Au^{198}, two independently assayed samples were used for each determination. For each isotope, duplicate samples were counted long enough to reduce the statistical error below 1%. Samples from separately assayed solutions counted in this manner yielded efficiencies that were in agreement within ±5%. The results are shown in Table 2.

Sensitivity. The minimum detectable activity for each well counter is given as a direct measure of the sensitivity of the counter. These values were defined as that specific activity that in total volumes of 4 cm^3 or 20 cm^3 for the small and large well crystals respectively would give 100 net counts per minute. This definition was made in preference to using one based upon the background counting rate because backgrounds are variable for different counter operations and shielding. The efficiency is generally the same for counters of the same type. With the background counting rates of the counters used in obtaining this data, net sample counts of 100 per minute will yield results with a statistical accuracy of ±5% for 20-min counts.

It is of interest to note the high efficiencies obtained with isotopes emitting gamma rays in cascade. This is particularly evident by comparing the results for Fe^{59} and Co^{60}. Fe^{59} emits 1.1- and 1.3-Mev gammas with a probability of 50% each. Co^{60} emits gammas of the same energy but in succession with a probability of ~100% each. The efficiency reported for Co^{60} is slightly less than twice that for Fe^{59} as would be expected on the basis of the chance for each gamma to be detected minus the chance of both being detected simultaneously.

* Kimble glass screw-cap vials have been found ideal for this purpose.

TECHNICAL BRIEFS

• **Structure of glass** study will be made under a fellowship established at MIT by Owens-Illinois Glass Co. By means of neutron bombardment, it is hoped to determine the structure of glass and possibly produce advantageous structural rearrangements. Neutron source will be Brookhaven reactor.

• **Cesium-137,** separated from waste fission products by ORNL Operations Division, has been pressed into two pellets, each ½ in. thick, 1¼ in. in diameter, and weighing a little more than an ounce; the two pellets, containing 1,540 curies of radioactivity, were sealed in a double jacket of stainless steel. The first pellets will be used in a teletherapy unit being prepared for cancer research in the Medical Division of ORINS.

• **Tracer techniques** have been applied by General Electric Phenolic Engineering Laboratory to determining erosion in metal molds caused by plastic compounds. One part metal per 20 million parts of plastics can be detected. A sprue bushing from a standard transfer mold is encapsulated and irradiated in BNL pile.

• **BF_3 proportional counter,** developed by Westinghouse for use in the Nautilus thermal reactor, was designed to be shockproof and to withstand temperatures up to 100° C. Sensitivity for thermal neutrons is about 4.5 counts/n/cm², using a filling of 55 cm Hg of enriched BF_3; counter remains usable in gamma fields up to 230 r/hr. Counter construction is welded aluminum; center wire is 0.001-in. tungsten.

• **Gantry-mounted linear accelerator** for X-ray treatment of deep-seated diseases is in operation in the Megavoltage Treatment Unit at General Hospital, Newcastle-upon-Tyne, England. Claimed to be the world's first such machine, it has an energy rating of 3.5–4 Mev.

Correction

References in "Growth Potential of the U. S. Nuclear Power Industry" (NU, June '54) on p. 15 to Fig. 3 and on p. 16 to Fig. 2 do not refer to illustrations in the article. The curves to which they refer were published on p. 73 (top left) of the May issue.

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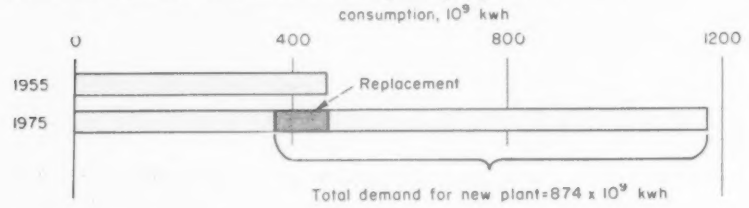

will be met at these generating costs. . .

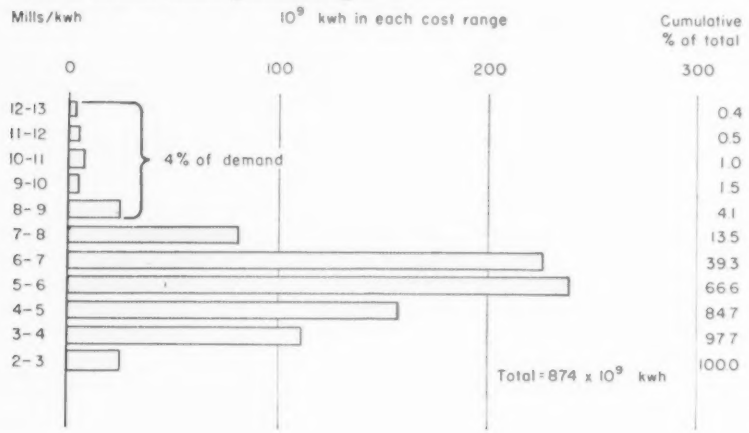

TABLE 1—Cost of Power from New Conventional Plants*

Generating cost (mills/kwh)	*Capacity (Mw)*	*Per cent of total*	*Cumulative per cent*
12–13	49	0.4	0.4
11–12	20	0.2	0.6
10–11	68	0.6	1.2
9–10	67	0.6	1.8
8–9	282	2.3	4.1
7–8	1,242	10.3	14.4
6–7	3,153	26.1	40.5
5–6	3,307	27.3	67.8
4–5	2,009	16.6	84.4
3–4	1,527	12.6	97.0
2–3	358	3.0	100.0
Total	12,082	100.0	100.0

*Includes all new postwar steam plants (but no additions to old plants). Not reflected is the market now served by internal combustion units. While generating costs from such units, representing about 2% of total U. S. production of electricity (and 3% of capacity) in 1952, are generally above 8 mills and run as high as 20 mills or more, the plant size is under 10 Mw and usually much smaller. To put plants on uniform capability basis, unit generating costs are computed on 12½% fixed charges, 95% plant factor. Prepared by AEC staff from data in "Steam-electric Plant Construction Cost and Annual Production Expenses, 5th Supplement," Federal Power Commission, Washington, D. C., 1952.

Power Costs: Nuclear vs Coal

To see just how reduction of nuclear-power costs will affect nuclear power's competitive position, the Atomic Energy Commission has examined costs of generating power from new conventional steam plants. These costs can be compared with the range of 4–7 mills sought from nuclear plants. Clearly, 4–7-mill nuclear power would be widely competitive.

The Federal Power Commission computed for the Joint Committee that in 1952 the average production cost of steam-generated electric power in the U. S. was 7.4 mills/kwh for the major utility systems. This average includes a wide range of costs for individual plants, varying with size, age, and efficiency of the plants and the extent to which they are used, the cost of fuel, and other factors. To see the competition nuclear plants must face, one must look not at this general average, but at the maximum performance of efficient new conventional steam plants, in comparison with which a nuclear plant would be evaluated by any management considering the kind of plant to build.

As shown in Table 1, the range of generating costs in new postwar utility steam plants is wide—from just under 3 mills/kwh to over 12 mills/kwh. But very little of the capacity (4%) in these new plants produces at more than 8 mills/kwh, and the plants that do are relatively small, the largest being 80,000 kw. Most of them are much smaller. Similarly, a minor part of the capacity (3%) can generate at less than 3 mills. Over 90% of the competition for nuclear power falls in the 3–8 mill range, and 70% falls in the 4–7 mill range that it is hoped will be achieved from nuclear plants.

If these cost ranges are applied to the expected growth in demand for electricity, we can obtain a picture of the market into which nuclear power will enter between now and 1975. The amount of electricity to be required is the consumption forecast by the Paley Commission, or 1,400-billion kwh in 1975, an increase to three and one-half times the 1950 consumption of 390-billion kwh. The potential market for nuclear power within this overall total is considered to be a share of the new demand to be supplied by steam plants, plus a share of the steam

generating capacity to be built to replace worn-out equipment. See Table 2 and the chart. Stability of generating costs is assumed, relying on continued increase in efficiency of conventional generating plants to offset rising costs of fuel. Examination of the potential market in this manner shows the importance of generating costs on the entry and rate of growth of nuclear power.

According to Federal Power Commission regions, the 1952 generating costs (mills/kwh) in large new postwar steam plants fall in the following ranges:

Northeast	5½–8½
East Central	4 –7
Southeast	3½–8½
North Central	5 –7½
South Central	2½–5½
West Central	4½–6
Northwest	4 –6½
Southwest	5½–7

TABLE 2—Estimated Costs and Energy from New Steam-Generating Capacity

Cost (mills/kwh)	*New capacity to be built during five-year periods from 1955–1975 (10^9 kwh)* '50–'55	'55–'60	'60–'65	'65–'70	'70–'75	*Total capacity, 1955–1975* (10^9 kwh)	(%)
12–13	–	1.0	0.7	0.8	0.7	3.2	0.4
11–12	–	0.3	0.3	0.3	0.3	1.2	0.1
10–11	–	1.2	1.2	1.2	1.2	4.8	0.5
9–10	–	1.2	1.0	1.1	0.9	4.2	0.5
8–9	–	5.5	5.7	5.7	6.0	22.9	2.6
7–8	–	22.5	20.8	19.8	18.9	82.0	9.4
6–7	–	58.5	56.0	54.9	56.2	225.6	25.8
5–6	–	65.0	58.3	56.9	57.7	237.9	27.3
4–5	–	40.2	38.3	38.9	41.0	158.4	18.1
3–4	–	25.8	27.8	29.3	31.0	113.9	13.0
2–3	–	4.8	4.9	5.1	5.1	19.9	2.3
Total new capacity	–	226.0	215.0	214.0	219.0	874	100.0
Capacity at beginning of period	288	465	647	819	989	465	
Total	–	691	862	1,033	1,208	1,339	
Less retired capacity	–	44	43	44	42	173	
Total capacity at end of period	465	647	819	989	1,166	1,166	

Nomograms for Uranium Burnup

By F. R. TARABA
Argonne National Laboratory
Lemont, Illinois

A series of nomograms has been constructed to solve the burnup equation, $B = E(1 - e^{-\sigma\phi t})$, where B = burnup of uranium atoms, %; $E = U^{235}$ enrichment, %; σ = thermal neutron cross section for fission of U^{235}, cm^2, assumed constant in constructing nomograms; ϕ = thermal neutron flux, $n/cm^2/sec$; t = irradiation time, sec.

Although the burnup equation is explicitly solved for B, any variable can be found easily by using the nomograms if the other variables are known.

Nomogram use is described in this article, and examples illustrate the procedure. Construction features are explained and limitations are evaluated.

Construction features. All nomogram scales are logarithmic. Two auxiliary scales, D and D' (associated with U^{235} burnup), make a curved scale unnecessary. While they are numerically equivalent, the scales identified with them are not geometrically equivalent.

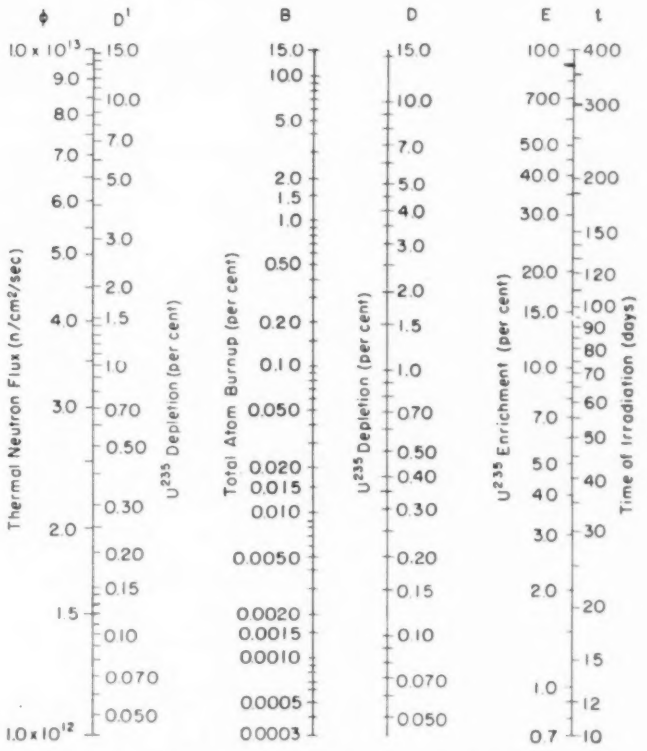

FIG. 1. Uranium burnup nomogram; $\phi = 10^{12}$ to 10^{13}, t = 10 to 400 days

Points associated with each of the variables have been scaled so that the combinations (ϕ, t, D) and (E, B, D') lie along straight lines.

Use. To solve for either of the variables ϕ or t, obtain D' as the intersection of the D'-scale and the straight line determined by the points E and B;

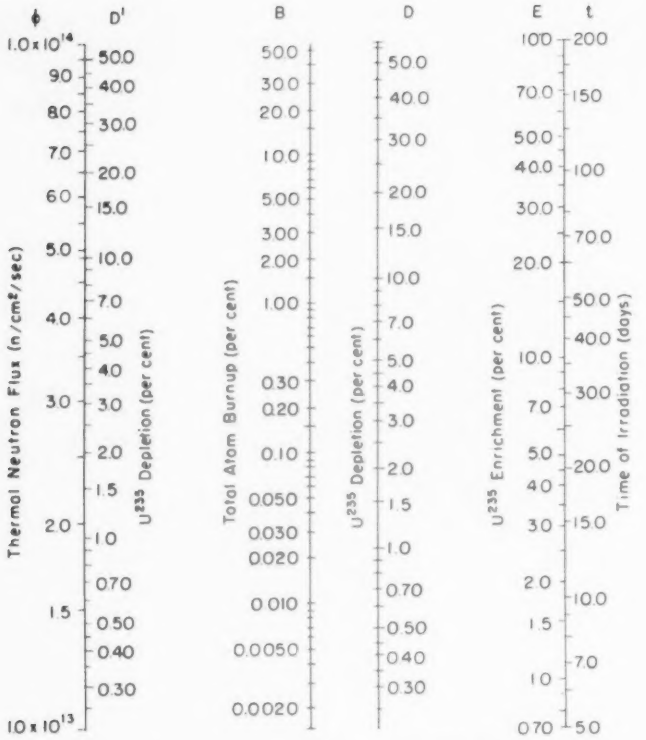

FIG. 2. Uranium burnup nomogram; $\phi = 10^{13}$ to 10^{14}, $t = 5$ to 200 days

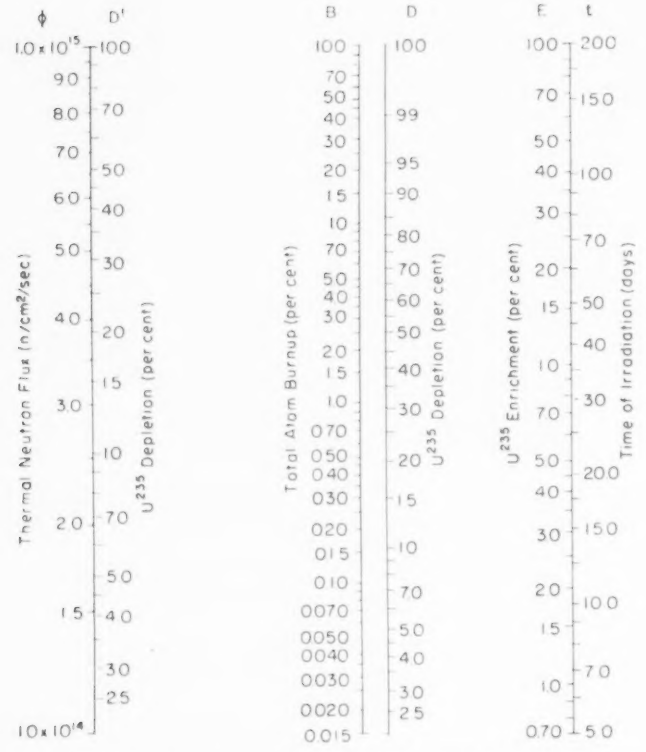

FIG. 3. Uranium burnup nomogram; $\phi = 10^{14}$ to 10^{15}, $t = 5$ to 200 days

Use of Nomograms

Variables		*Steps*	
Known	*Unknown*	*First*	*Second*
ϕ,t,E	B	$\phi \times t = D$	$D' \times E = B$
ϕ,t,B	E	$\phi \times t = D$	$D' \times B = E$
ϕ,E,B	t	$E \times B = D'$	$D \times \phi = t$
t,E,B	ϕ	$E \times B = D'$	$D \times t = \phi$

locate the value of D' on the D-scale; locate the value of the desired variable, ϕ (or t), at the intersection of the ϕ-scale (or t-scale) and the straight line determined by the points D and t (or ϕ).

To solve for either E or B, obtain D as the intersection of the D-scale and the straight line determined by the points ϕ and t; locate the value of D on the D'-scale; locate value of the desired variable, B (or E), at the intersection of the B-scale (or E-scale) and the straight line determined by the points D' and E (or B).

The procedure for solving the burnup equation is expressed symbolically in the table.

The use of the auxiliary scales in conjunction with the other variables is shown by examples.

Example 1. Given that $\phi = 3.5 \times 10^{13}$ n/cm²/sec, $t = 100$ days, and $E = 10\%$ (by weight). Find the total atom burnup, B. 1, refer to nomogram of proper range; 2, find $D = 13.5\%$ at the intersection of the D-scale and the straight line determined by the points $\phi = 3.5 \times 10^{13}$ and $t = 100$; 3, locate the value of D on the D'-scale; 4, find $B = 1.4\%$ at the intersection of the B-scale and the straight line determined by the points $D' = 13.5\%$ and $E = 10\%$.

Example 2. Given that $B = 2.0\%$, $E = 5\%$, $t = 60$ days. Find the thermal-neutron flux. 1, refer to nomogram of proper range; 2, find $D' = 40\%$ at the intersection of the D'-scale and the straight line determined by the points $B = 2.0\%$ and $E = 5\%$; 3, locate the value of D' on the D-scale; 4, find $\phi = 2 \times 10^{14}$ at the intersection of the ϕ-scale and the straight line determined by $D = 40\%$, $t = 60$ days.

Discussion. The ranges of the nomogram scales are great enough for solving many problems. However, the range of any scale (except the D-scale) can be extended quite simply, because the scales are logarithmic.

A value of 484 barns is used as the

corrected thermal neutron cross section for fission of U^{235}. It represents the effective cross section for fission if it is assumed that the thermal neutron flux has a Maxwellian distribution.

The depletion of the U^{235} is considered to be accomplished as a result of fission only. Also, the total atom burnup refers only to U^{235} burnup.

In using the alignment charts, an error greater than $\pm 5\%$ is very unlikely if care is exercised in locating points on the various scales. This error is smaller than the probable error accumulated from other uncertainties occurring during uranium irradiation.

NUCLEAR POWER

• **Uranium fabrication** process developed in Belgium under the direction of J. Van Impe is said to permit more economical preparation of high-purity fuel elements. It is expected that unclad slugs or sheets can be produced for about $10/lb in Europe, or for $20–30/lb in the U. S. Present U. S. prices for the unclad material are considered to be about $35/lb.

Laboratory production on a 20-kg scale has been completed. Continuous processing, together with Zr canning (now in advanced development in Belgium) would expedite European construction of D_2O- and beryllium-moderated "PWR-type" natural-uranium power reactors.

Starting material for the new process is pure oxide UO_4 precipitated by H_2O_2 from uranyl nitrate purified by ether extraction. Calcination produces UO_3. Reduction with hydrogen gives UO_2.

Fluorination of the UO_2 with inexpensive nontoxic ammonium bifluoride is an important feature of the technique. The NH_4HF_2 can be recycled, gives a high metal reduction yield, and does not require use of expensive furnace linings needed when using gaseous hydrofluoric acid.

The process is continued by vacuum decomposing to get UF_4. Calcium reduction yields uranium metal, which can be vacuum cast into bars having variable and large grain diameters. The metal can be rolled into sheets; ingots can be extruded or rolled.

Tests in British and U. S. reactors have shown the metal to be excellent in its thermal-neutron absorption characteristics. The high average density (19.02 as compared to the normal 18.73) probably is due to low carbon and nitrogen content.

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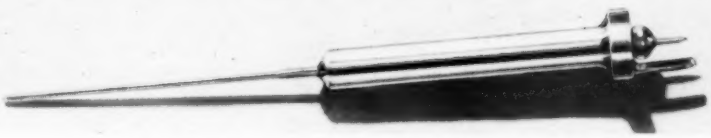

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BOOKS

Neutron Optics

By D. J. HUGHES (Interscience Publishers, Inc., New York, 1954, vii + 136 pages, $2.50). Reviewed by A. WATTENBERG, Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Mass.

This very nicely written monograph will be found useful by the wide audience to which it seems to be addressed. Those who are teaching courses in modern physics will find this booklet provides beautiful examples of the complimentarity of the wave and particle natures of matter. The sections on the index of refraction and the total reflection of neutrons by a mirror can certainly be used by seniors and graduate students without having to read the entire text. The author distinguishes between coherence and incoherence from an essentially phenomenological point of view. Many teachers may find it desirable to supplement this introductory section of this booklet if they plan to use Dr. Hughes' review more extensively.

The construction of research reactors at many universities will make available to many scientists the techniques of neutron optics. Those considering employing these techniques, whether physicists or nonphysicists, will find this monograph very valuable. Dr. Hughes has brought out the important points and mentions the difficulties involved in the use of neutron optics. He covers the successful application of total reflection, crystal diffraction, powder diffraction, liquid diffraction, and small-angle scattering of neutrons. He also points out what he considers the most promising fields for the future application of these techniques. The monograph is well referenced for those whose needs require them to investigate questions more deeply.

This booklet will be very helpful to those in the AEC who are training others. A need has existed for quite a while for a review that would integrate the applications of neutron optics to nuclear physics, solid state physics, crystal structure, and magnetic problems. Dr. Hughes, in writing this review, not only fulfilled this need, but did it very concisely and in a very nice style.

This is the first of a series of tracts on physics and astronomy. Therefore, it is perhaps appropriate to compliment Interscience Publishers for their efforts in making available inexpensive technical books. However, it is to be hoped that other publishers will not assume that the appearance of such monographs removes the need for a full-sized text in such a growing and useful field as neutron optics.

BOOKS RECEIVED

Noise, by Albert van der Ziel, Prentice-Hall, Inc., New York, 1954, xi + 450 pages, $10.35. *(To be reviewed.)*

The Quantum Theory of Radiation, 3rd ed., by W. Heitler, Oxford University Press, London, 1954, xiii + 430 pages, $7.20. *(To be reviewed.)*

Physical Aspects of Betatron Therapy, by John S. Laughlin, Charles C Thomas, Springfield, 1954, xiv + 98 pages, $3.75. *(To be reviewed.)*

The Permanent Revolution in Science, by Richard L. Schanck, Philosophical Library, New York, 1954, xvi + 112 pages, $3.00. This book develops the theme that, since Copernicus designated the earth as a satellite of the sun, a scientific methodology has emerged that is not satisfied with a purely mechanistic viewpoint. This method is to "study systems as developing societies of trends, in which each trend describes events in a collectivity without predicting the behavior of the individual elements out of which the collectivity is made."

Engineering Analysis, by D. W. Ver Planck and B. R. Teare, Jr., John Wiley and Sons, Inc., New York, 1954, xii + 344 pages, $6.00. This book discusses the professional approach to defining and solving engineering problems. Included are dynamics of translation and rotation, electric circuits, heat transfer, linear differential equations with constant coefficients, power series, graphical and numerical integration, hyperbolic functions, and evaluation of indeterminate forms.

Essays in Science, by Albert Einstein, Philosophical Library, New York, 1954, xi + 114 pages, $2.75. This abridged edition of "The World as I See It," published in 1933, is restricted to papers dealing with science. The essays include *Principles of Research; On Scientific Truth; Niels Bohr; On the Theory of Relativity; The Problem of Space, Ether, and the Field in Physics;* and *Notes on the Origin of the General Theory of Relativity.*

Molecular Theory of Gases and Liquids, by J. O. Hirschfelder, C. F. Curtiss, and R. B. Bird, John Wiley and Sons, Inc., New York, 1954, xix + 1219 pages, $20.00. By the statistical mechanical approach to molecular properties, this book describes the properties of gases and liquids. Following an introductory section, there are major divisions: *Equilibrium Properties, Non-Equilibrium Properties,* and *Intermolecular Forces.* The book should be useful to students in chemical physics, experimental physical chemists and industrial engineers, and statistical mechanicians and theoretical chemists.

ALSO OF NOTE

Transactions of the Symposium on Fluid Mechanics and Computing, Interscience Publishers, Inc., New York, 1954, 243 pages, $5.00. This book contains all of the papers, except one, delivered at the first symposium in applied mathematics sponsored by the American Mathematical Society and the Office of Ordnance Research, New York University, April 23 and 24, 1953. Topics covered are in the fields of mathematics, fluid mechanics, mathematical physics and computer techniques.

The Properties of Tin. This 55-page pamphlet is a revision of the original edition published in 1934. Data presented on pure tin is atomic and nuclear, physical, physico-chemical and metallurgical. Data for tin alloys are covered in a separate publication. *Tin Research Institute, Inc., 492 W. 6th Ave., Columbus 1, Ohio, $0.65.*

Nuclear Engineering—A Selected List of References (TID-3055). This bibliography contains 480 annotated references to AEC reports and to the open literature. Author index and report number index with availability information are also included. Individuals affiliated with the U. S. atomic energy program may obtain copies from the Technical Information Service through the usual channels. Others should obtain copies from: *American Institute of Chemical Engineers, 50 E. 41st St., New York, N. Y.*

Air Pollution Abatement Manual. This manual provides information on types of air pollution, legislative re-

quirements, and technical methods of handling problems, and suggestions for enlisting the cooperation of employees, industrial and public officials, and the public. Single complimentary copies will be supplied to governmental officials charged with air pollution control responsibilities. For others, the price is $6.00 (individual chapters are $0.15 to $0.75). *Manufacturing Chemists' Association, Inc., 1625 Eye St., N. W., Washington, D. C.*

AAAS symposium publications. Three volumes are available based on symposia conducted by the American Association for the Advancement of Science: "The Present State of Physics" (1949 meeting, New York, $6.75, AAAS members' prepaid order price $5.75), "Monomolecular Layers" (1951 meeting in Philadelphia, $4.25, members' prepaid order price $3.75), and "Astronomical Photoelectric Photometry" (1951 meeting in Philadelphia, $3.75, members' prepaid order price $3.25). *AAAS Publications, 1515 Massachusetts Ave., N. W., Washington 5, D. C.*

Potentiometer Handbook. This 207-page handbook treats potentiometer theory, design, performance, and application. Additional releases to be included in the loose-leaf binder will be sent at no additional charge. *Technology Instrument Corp., 531 Main St., Acton, Mass., $2.00.*

Business Opportunities in Atomic Energy. This report presents papers and discussions from a March '54 meeting held under the auspices of Atomic Industrial Forum, Inc. Topics covered are: atomic energy materials available for industrial use; potential uses of atomic energy; consulting and nonprofit research services; government services available to industry; and products required by the atomic energy industry. *Atomic Industrial Forum, Inc., 260 Madison Ave., New York 16, N. Y., $6.00.*

Films of nuclear studies. Three films are available: "Radioisotopes, Their application to Humans as Tracer Studies and for Therapeutic Use" (32 minutes); "The Atomic Apothecary, Radioisotope Research in Biology and Medicine" (38 minutes); and "Occupational Health Problems" (48 minutes). Rental is $25.00 each; purchase prices are $335.00, $295.00, and $495.00, respectively. *Medical Film Guild, Ltd., 506 W. 57th St., New York, N. Y.*

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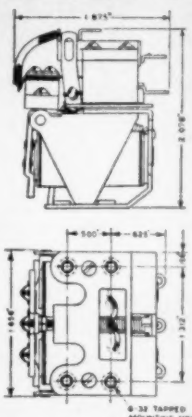

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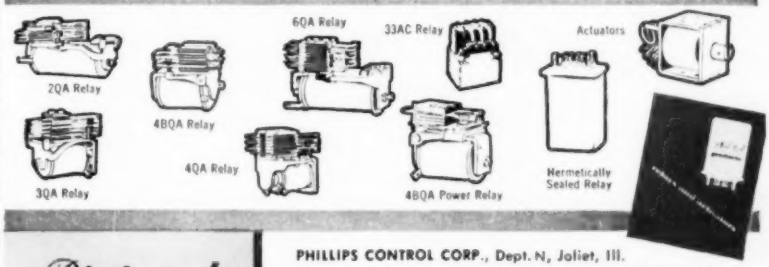

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NEWS

U. S. Aid Helps Belgium Build Its First Reactor; Bargaining Underway for More Information

Belgium's initial experimental reactor, now under construction at Mol, is the first concrete example of how U. S. technology may be used to foster nuclear power development in foreign nations.

It is an example, too, of how the 1946 Atomic Energy Act has restricted exchange of U. S. nuclear information with foreign countries. Even though the Belgian Congo has furnished some 70% or more of the raw uranium used in the entire U. S. atomic energy program, Belgian atomic development lags far behind that of several of her European neighbors.

The Belgium reactor will be a graphite-moderated, water-cooled affair with a power level of around 3,500 kilowatts. In design it will be based largely on the X-10 isotope producer at Oak Ridge National Laboratory, which Belgian scientists have visited and studied. The X-10 is air cooled.

Natural uranium fuel elements to be used in the Belgium reactor are U. S.-fabricated and the graphite was furnished by Britain.

Belgium's struggle to get started in the nuclear power race has hinged mainly on diplomatic negotiations with the U. S.—and an occasional nudge from Belgian technicians.

Belgium and U. S. officials sit down this year to negotiate extension of the ten-year Congo uranium agreement. It's a sure bet the Belgians will attempt to gain some of the information and material they badly need to catch up with such nations as Norway, The Netherlands, and France. The Belgians would already have had that information if the 1946 U. S. law had not forbade the export of either the technology or the key materials.

While pleading continually for U. S. nuclear power technology, Belgium has lived up to the 1944 uranium supply contract it signed with the U. S. and Britain in 1944. The agreement—a wartime contract—provided that the Congo uranium output would be divided between the U. S. and Britain.

Although the actual wording of the agreement is still as guarded as an H-bomb formula, it has been learned that the natural uranium furnished was to go exclusively for military efforts (NU, Nov. '52, p. 105). Subsequent negotiations have protected this U. S. source, and provided higher monetary return for the Belgians.

For the past three years, the Belgians have been bearing down on U. S. officials for more technical information and processed uranium. In at least two ways, this has paid off.

Two years ago the U. S. agreed to send Belgium 30 tons of uranium fuel elements suitable for use in a power reactor. At the same time Britain came through with enough refined graphite to moderate the fission in such a reactor.

But whether this was an outcome of hard negotiations or for some other reason, various sources disagree. U. S. officials say they have always tried to give Belgium what consideration they could under the Atomic Energy Act. The fuel elements—processed and fabricated from natural uranium—were furnished well within the letter and spirit of the law, although this would not appear to conform with restrictions on exchange of industrial information.

Certain Belgian sources have another explanation. They say the U. S. fuel element shipment came only after Belgian metallurgists had perfected a fuel element which ranked with the best natural uranium elements produced by either the U. S. or Britain. According to this theory, the shipment was aimed at discouraging further Belgian progress along this line. A paper presented by a Belgian metallurgist at the International Nuclear Engineering Conference in Ann Arbor, Michigan, in June tells of Belgian accomplishments in fuel element fabrication, but gives no

Invite 33 Fixed-Price Bids on Package Power Plant

Formal invitations to bid on an Army "package" nuclear power plant were scheduled to go to 33 industrial firms or groups last month. The bids were to be requested on a fixed-price basis. All other reactors built to date have been built under cost-type contracts.

The 1,250-electrical-kw reactor will be the prototype for a plant to be built at a remote military site, probably in the Arctic. The cost of it is expected to be of the order of several million dollars.

The successful bidder will be required to guarantee minimum performance of the plant. It is not expected that the engineering contractor will have to guarantee the fuel elements. These will be provided by the government, probably through another contractor.

The following firms were to receive invitations to bid:

- Allis-Chalmers
- American Locomotive
- American Machine & Foundry
- Babcock & Wilcox, Vitro Corp. (joint)
- W. F. & J. Barnes
- Bendix
- Bethlehem Steel Corp. (Shipbuilding Div.)
- Blaw-Knox
- Combustion Engineering
- U. S. Steel (Consolidated Western Steel Div.)
- Donovan Construction Co., Winston Bros. Co., C. F. Lytle Co., Green-Construction Co., Missouri Valley Constructors, Inc. (joint)
- Fairbanks, Morse
- Fluor
- Ford Instrument
- Foster-Wheeler
- General Electric
- Kaiser Engineers
- Walter Kidde
- Kuljian Corp.
- A. D. Little
- AVCO Mfg. Co. (Lycoming Div.)
- Glenn L. Martin
- Merritt, Chapman & Scott
- Newport News Shipbuilding and Drydock Co.
- North American Aviation
- Ralph M. Parsons
- Raymond Concrete Pile Co.
- Stearn-Roger Mfg. Co.
- Sverdrup & Parcel, Food Machinery & Chemical Corp. (joint)
- M. H. Treadwell Co.
- Westinghouse Air Brake Co.
- Westinghouse Electric
- Curtiss Wright

hint that the work was responsible for the U. S. shipment.

In addition to materials, the U. S. also permitted a group of Belgian scientists and technicians to study an experimental power reactor at AEC's Oak Ridge, Tenn. installation.

Armed with the fuel elements, graphite and the information, the Belgians scaled up their atomic power plan—going from a zero power reactor to a 3,500-kw experimental reactor. But that's just the beginning for them.

What they want badly is some of the knowhow which U. S. engineers have accumulated in building the power plants for the first atomic submarine—The Nautilus. With that kind of information and some more fuel elements, they'll be ready to start on their first full-scale power plant.

While Belgium waits for the U. S., the British are forging ahead using Belgian uranium to build Europe's first big atomic power plants.

American Locomotive Co. Forms Atomic Projects Unit

With the value of its atomic energy products surpassing annual locomotive sales for many of the prewar years, the American Locomotive Co. has established an atomic energy projects department. Kenneth Kasschau has resigned as director of the research and medical division of the Atomic Energy Commission's Oak Ridge operations office to supervise the new unit.

Since 1949, the company has been producing nickel-clad steel pipe for AEC. The corrosion-resistant pipe is used in processing and separations plants. Alco's Dunkirk, New York, plant manufactured this pipe for three gaseous diffusion plants (NU, Jan. '53, p. 74), and also supplied the Savannah River heavy-water plant with fabricated heat exchangers and tube bundles, other Alco products.

The Dunkirk plant also produces gaseous-diffusion gas converter subassemblies, and evaporators, coolers, and condensers for atomic energy installations.

Britain Passes U. S. in Shipping Isotopes

Recently released figures show that Britain's Atomic Energy Research Establishment at Harwell has made

Washington Report

The bill to amend the Atomic Energy Act of 1946, as introduced in both Houses of Congress, contained the following changes over the final version released by the Joint Committee on Atomic Energy before the bill was reported out **(see page 5 for Senate, House action on bill)****:**

- Each member of the AEC "shall have equal responsibility and authority in all decisions and actions" but the chairman "shall be the official spokesman of the Commission." Although it is implied, there is no statutory requirement that each commissioner will have equal access to information.
- In carrying out research for others, AEC need not charge any fees.
- If they follow the law, licensed operators of nuclear power plants can be assured of a supply of fuel for the period of their license.
- In addition to the initial cost of fuel to the licensee, AEC will be able to charge for fuel that is consumed in a reactor.
- The government will not be responsible for accidents resulting from licensee's possession of fissionable material (apart from his use of it).
- All sellers of Pu^{239} or U^{233} to the government will receive the same "fair" price. The government will be permitted to enter into contracts for periods up to seven years.
- AEC may distribute natural uranium and thorium "outside the United States" without clearing through the President and Congress.
- Individuals and organizations are prevented from exploiting uranium deposits with knowledge gained from prior government affiliation.
- In the distribution of radioisotopes, AEC shall seek to encourage research and development.
- The Department of Defense may not engage in the primary production of fissionable material.
- AEC shall impose "minimum" regulations in administering medical and research licenses.
- Antitrust safeguards of the McMahon Act are restored. AEC must notify Attorney General and Federal Trade Commission prior to issuance of any license that might be inconsistent with antitrust laws. Decisions in such cases would be made by FTC, subject to court appeal.
- AEC may issue licenses for the manufacture and export of components for power reactors and research reactors.
- AEC may not reject license applications because the licensee's activities would result in the production of fissionable material beyond the nation's needs.
- The Joint Committee on Atomic Energy may not waive its consideration of any proposed international agreement.
- The President is specifically authorized to set up an "international atomic pool."
- The Department of Defense may give other nations information on the external characteristics of atomic weapons.
- A major change is requirement of compulsory licensing of patents on inventions of "primary importance" where such licensing is necessary to "effectuate the policies and purposes" of the law. AEC and any authorized person may then use such licenses. The owner of the original patent shall be entitled to a "reasonable royalty fee." Compulsory licensing shall be in effect until Sept. 1, 1959.
- A Patent Compensation Advisory Board shall be established.
- The AEC General Advisory Committee shall initiate recommendations for granting awards for "especially meritorious contributions" in the atomic energy field.
- In issuing licenses for power reactors, AEC shall give "preferred consideration to applications for such facilities which will be located in high-cost power areas."
- Revocation of licenses for false statements in applications is made more difficult.
- Penalty for inadvertent publication of restricted data has been dropped.

Sidelights

National Lead operates AEC laboratory. The Winchester, Mass., raw materials development laboratory, operated by American Cyanamid Co. for AEC since 1951, is now managed by National Lead Co. Principally concerned with processes for treatment of uranium-bearing ores in production of uranium concentrates, the laboratory was moved from Watertown, Mass., last year.

•

Argentina has 14 medical research centers. Use of radioisotopes in diagnosis and therapeutics is being studied at 9 of 14 research centers now active in Argentina. Principal problem is treatment of goiter, which is endemic in two of the country's provinces. The remaining 5 research units are carrying out biological research; 4 additional units will augment their activities shortly.

•

Beltsville producing radioactive fertilizer. One ton of P^{32}-containing fertilizer will be produced at the Department of Agriculture research station near Beltsville, Md., this year. Cost is estimated at $25,000; the fertilizer will be supplied without charge to qualified agricultural research workers.

•

Peaceful thermonuclear energy a "certainty." Australian nuclear physicist Marcus Oliphant is quoted as saying he is absolutely certain that energy from the hydrogen fusion reaction will be available in the near future. He suggested in Auckland, that New Zealand, with its supply of heavy water, could be the first country to use this energy for peaceful purposes.

•

Stockholders approve Dynamics-Convair merger. Consolidated Vultee Aircraft Corp. will operate as a division of General Dynamics Corp. as a result of their recent merger. Dynamics' Electric Boat Division built the nuclear-powered submarine *Nautilus*, is building the *Sea Wolf;* Convair is studying nuclear propulsion for aircraft.

•

Australian AEC gets research laboratories. Sydney has been selected as the site for recently authorized Australian Atomic Energy Commission special research laboratories. Research in universities or elsewhere in Australia will not be duplicated; technology of nuclear energy will be studied.

•

General Electric expands research laboratory. New construction and equipment totaling about $13-million is being added to the General Electric Research Laboratory near Schenectady, N. Y. A $3.7-million metallurgy and ceramic laboratory is nearly finished. Staff will be increased 50% by 1958 to 500 scientists, 1,000 service and administrative personnel.

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Cancer research applications due October 1. Acting for the American Cancer Society, the Committee on Growth of the National Research Council is accepting applications for grants-in-aid for cancer research in the United States. Grants become effective July 1, 1955; applications are due October 1.

•

Radiography delineates Japanese art development. Ancient Buddha statues in Japanese temples were radiographed with Co^{60} recently to guide repair of structural defects. Technique also revealed casting position and methods, making it possible to date statues and establish sculptor's name.

•

Course for medical radioisotope technicians. R-C Scientific Instrument Co. is sponsoring a School of Radioisotope Technology at 305 Culver Blvd., Playa del Rey, Calif. A 12-week training course in isotope techniques for medical technicians will be given three times a year.

•

Five courses in radiological health. The training program at the Robert A. Taft Sanitary Engineering Center, 4676 Columbia Pkwy., Cincinnati, Ohio, includes the following courses: Nov. 1–5 and May 16–20 (1954), problems of radioactivity in waterworks; Jan. 10–21 and April 18–29 (1955), basic course in radiological health; Jan. 24–Feb. 4, occupational radiation protection; March 7–10, radiation hygiene and preventive medical aspects; May 2–13, environmental radiation sanitation course. The Center is a division of the U. S. Public Health Service.

more shipments of isotopes for three consecutive years than the United States' Oak Ridge National Laboratory. Britain lags less than 1,000 behind in total shipments, even though ORNL had a year's head start.

The figures compare as follows. Figures for the U. S. include shipments from ORNL only; radioisotopes produced at Brookhaven and Argonne National Laboratories and in the Materials Testing and Hanford reactors are not included. But the number of shipments from the latter is small, although total activity is high.

Year	*British shipments*	*U. S. shipments*
1946	.....	246
1947	135	1,652
1948	1,414	2,644
1949	3,060	4,370
1950	6,169	6,234
1951	8,755	7,825
1952	10,160	9,102
1953	12,159	10,676
Totals	41,852	42,749

Comparative figures for the amount of activity contained in the shipments are not available at present.

AEC, Navy Expand Program for Leakproof Pumps

To develop alternate sources of supply for leakproof pumps, the Atomic Energy Commission and the Department of Navy have invited bids for construction of ten units. Developmental models of the canned electric-motor-driven units are now in operation at the Westinghouse-operated Bettis Plant, Pittsburgh, Pa.

AEC intends to buy four pumps with a capacity of 150 gal/min of hot water under 2,200 lb/in^2 pressure and two pumps with 30-gal/min capacity. The Navy expects to buy four of the 150-gal/min size.

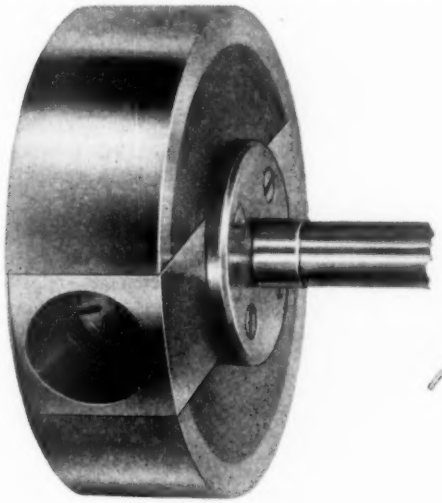
Firms interested in bidding can obtain details from AEC's Pittsburgh Area Office, Box 1105, Pittsburgh 30, Pa., or the Contract Division, Bureau of Ships, Navy Department, Washington 25, D. C.

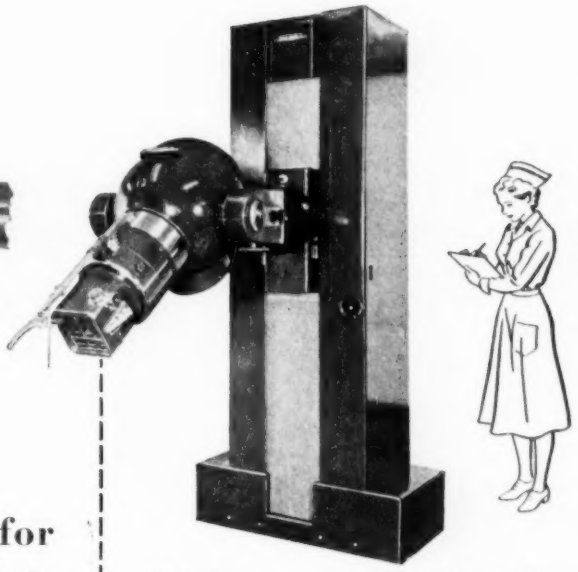
Larger pumps of the same type, with 4,000-gal/min capacities, are already in use by both AEC and Navy. Similar 16,000-gal/min pumps will be used in the PWR power plant to be built near Shippingport, Pa. (NU, July, 54, p. 48).

The motor driving a pump of this type consists of a squirrel-cage rotor protected from the water by an Inconel

Mallory 1000 Metal Shield

harnesses radiation from "hot" cobalt





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By utilizing the superior radioactive shielding characteristics of Mallory 1000 Metal, the Picker X-Ray Company designed greater safety and flexibility into their Picker Co^{60} Teletherapy Unit. Used for treatment of cancer and other diseases, this unit gets its energy from radioactive cobalt, a few wafers of which have the power of 3-million volt x-ray.

The cobalt 60 radiates continuously. To control its radiation for safe, flexible treatment, a special "switch" was designed of Mallory 1000 Metal as shown here. Into the block goes a receptacle, also of Mallory 1000, which holds the cobalt source. Effectively confined by its shield, radiation can come out only through a narrow hole in the receptacle. This compact assembly is mounted inside a lead ball. By rotating the Mallory 1000 shield, radiation can be allowed to come out through an aperture in the ball or can be "switched" off.

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jacket, turning within a stator similarly clad. Water being pumped fills the space between rotor and stator and supplies the only lubrication for the internal bearings.

Russia Trails U. S. in Power Reactor Work

Russian development of nuclear power for industrial purposes appears to be trailing U. S. progress by at least a year and possibly more.

This comment came from several top U. S. nuclear scientists following the Moscow broadcast announcing operation of Russia's first 5,000-kw nuclear power plant. The statement came from the Soviet Council of Ministers.

The first report gave few details: "On 27th June 1954," the announcement said, "the atomic energy power station began working and producing electric current for industry and agriculture in the neighboring region." Capacity of the plant, said the report, is 5,000 kilowatts.

Soviet scientists and engineers were also reported working on larger nuclear plants with capacities ranging from 50,000 to 100,000 kilowatts.

While the U. S. Atomic Energy Commission kept an official silence on the Russian announcement, qualified sources within AEC saw no reason to doubt the claim. Since U. S. officials have previously disclosed Russian A-bomb and H-bomb tests, there is reason to believe the Russians have sufficient skill and knowledge to control the fission process for electric power production.

One official whose job it is to keep informed on Soviet nuclear progress termed the announcement "a rather modest one." He pointed out that the land-based prototype of the first (U. S.) atomic submarine engine is of a comparable power level and has been operating near Arco, Idaho for more than a year.

Electric power has been generated from the experimental breeder reactor of the Argonne National Laboratory in Idaho and from the homogeneous reactor experiment at Oak Ridge. Electrical capacity of these experiments was around 250 kilowatts.

The first full-scale U. S. nuclear power plant (the PWR) is in the advanced design stage at Westinghouse Electric Corp. When constructed it will have a minimum capacity of 60,000 kilowatts of electric power.

Key question posed by the Russian announcement was whether the nuclear power plant was an attempt to produce economic power. If cost or effort was not considered, American nuclear scientists thought the Russian claim might be a hollow one so far as propaganda is concerned.

Curious scientists had a number of subsidiary questions: What type is it? Is the claimed capacity in terms of heat or electric power?

Washington officials considered the Russian announcement, in part at least, another propaganda move to win the attention and friendship of small power-hungry nations.

It should be pointed out, however, that AEC decided to go ahead with the PWR mainly to show the world that the U.S. has a strong interest in civilian nuclear power. If the Russian plant is an actuality, and is producing exclusively for industry, it would, in fact, be the largest such plant in the world, even though it is quite small.

1,200 Attend First Major U. S. International Nuclear Engineering Conference; Interest in Subject High

Evidence of tremendous worldwide interest in all aspects of nuclear power development was brought out at Ann Arbor, Michigan, in June at the American Institute of Chemical Engineers' International Congress on Nuclear Engineering. A total of 1,200 scientists and engineers registered for the meeting, including 120 from 16 foreign nations, making this the largest such conference ever held.

Subjects covered included all phases of reactor technology and many aspects of radioisotope applications. Although secrecy limited what could be reported on, there were a number of papers that were specifically declassified for this meeting. These included some on specific reactor designs and on separations technology.

One of the most striking aspects of the meeting was the large turnout of foreign scientists. The 16 countries officially represented were: Argentina, Australia, Belgium, Brazil, Canada, France, India, Italy, Japan, Mexico, Netherlands, Norway, Spain, Sweden, Switzerland and United Kingdom.

Almost every one of these countries has a vigorous atomic energy program. Their delegates showed that, although they are hampered by restrictions on information dissemination from this country, they have made very considerable progress on their own.

The meeting had sessions on research and educational reactors, fuel refining and preparation, separations technology, waste disposal, heat transfer, structural materials, kinetics, design and operating problems, uses of radioactive products, automatic computation, and the social impact of nuclear energy.

Design and operational features that insure flexibility in research reactors were shown for the Penn State, University of Michigan, Naval Research Lab, Watertown Arsenal, new Oak Ridge Research, CP-5, Swedish, and North American Aviation research reactors. Operational characteristics of the Dutch-Norwegian reactor and the Los Alamos water boiler were explained. The failure and disassembly of the Los Alamos Fast reactor and the restoration of the NRX were described. Structure temperatures of the MTR, the Saclay pile's cooling system, and ten years operating experience with the X-10 pile were presented. Corrosion and impurities in the D_2O system of the Dutch-Norwegian reactor and design features of the EBR, HRE, Zephyr, and SGR were explained. Studies connected with Brookhaven's liquid-metal-fuel reactors were described (NU, July '54, p. 11).

Preparation, properties, and uses of beryllium, zirconium, graphite, and heavy water were covered as were the effects of radiation on water and metallic and nonmetallic materials.

Other sessions included descriptions of uranium-oxide liquid-fuel reactors, problems pertinent to use of NaOH, the importance of exponential experiments, methods for appraising and optimizing reactor designs, means of obtaining economic power from fast reactors, principles of reactor-heat removal, optimum coolant and temperature selection, and recombination of radiolytic gas from aqueous reactors.

Also included were descriptions of pumps, manipulators, nonuniform fuel distributions, approximations of fast reactor and uranium-graphite reactor kinetics, use of analog and automatic computer techniques for flux distribution and reactor-dynamics analyses.

Sessions on separations processing of

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Tracerlog No. 58, available on request, contains complete information.

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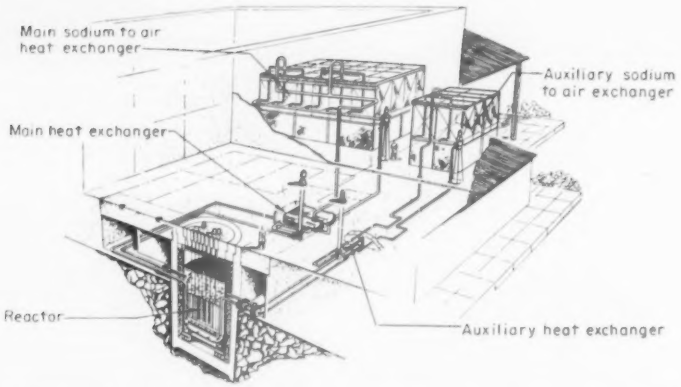


$10-MILLION COST of experimental sodium-graphite power reactor will be shared by Atomic Energy Commission and North American Aviation, Inc. Terms of recently signed contract provide that company will assume up to $2.5-million of cost, also will operate plant for about two years. Target date for operation is 1957; reactor will produce 20 Mw heat, will not have electricity-generating equipment (NU, May '54, p. 72)

irradiated materials included discussions of radiochemical process development and pulse-column techniques. A louver-plate redistributor for large-diameter columns was described.

Eisenhower Signs Bill Giving AEC $1.2-Billion

Funds for operating Atomic Energy Commission facilities in fiscal-1955 greatly exceed those for plant and equipment. The Independent Office Appropriation Bill providing the money was signed by the President on June 30.

Of the $1,209,844,700 total funds approved for the year starting July 1, $1,098,962,000 is for operating expenses; only $110,882,400 is allotted to capital increase in plant and equipment. Capital spending has peaked (NU, Mar. '54 p. 74) and is on the way down as AEC winds up its expansion program. Operating expenses, however have increased with the expansion of facilities.

Operating funds include $1,800,000 for physical research (the Senate had proposed $3,100,000), $435,000 for biology and medicine, and $3,265,000 for increase of stores and inventories. These figures are compromises between House and Senate appropriations figures (NU, May '54, p. 75).

Plant and equipment funds are about a 50-50 compromise between a lower House figure and a higher Senate amount. While larger than the $96,498,000 AEC requested, this is far below the $236,350,000 appropriated for the previous year.

The increase over the amount originally voted by the House includes $5,150,000 for new processing plants; the Senate originally proposed $12-million. As part of the compromise, the final appropriation provides that money for such plants can be used only if private financing is not available. Plant construction cannot start without AEC obtaining approval from the appropriations committees.

The total appropriation, while $132-million less than AEC requested for fiscal 1955 (NU, June '54, p. 84), tops fiscal 1954's total by $152-million.

CISE Is Planning Italian Power Reactor

A government unit, the National Committee for Nuclear Research, has assigned the job of planning the first Italian nuclear reactor to CISE, an experimental center financed by industrial grants (NU, Dec. '52, p. 18).

The reactor will be built near Milan. Its projected cost is $8-million. Power level will be 10 Mw, according to a plan CISE has submitted based on preliminary studies.

The heterogeneous reactor will use 5–6 tons of unenriched metallic uranium for fuel and 10–12 tons of heavy water as moderator and pressurized coolant. Its cylindrical core will be contained in an aluminum tank surrounded on sides and bottom by a graphite reflector.

CISE, in connection with the reactor study, has carried out experiments on heavy-water production and uranium metallurgy. The national committee has assigned CISE the task of organizing pilot plants for heavy-water production and for extracting metallic uranium from uranated ammonia to be supplied by private industry. CISE probably will build the reactor, but no definite assignmemt has been announced.

Ask 17 Foreign Leaders to Address NICB Meeting

Official representatives of atomic energy programs of 17 foreign countries have been asked to address the Third Annual Conference on Atomic Energy in Industry, October 13–16. The 16-session meeting in the Hotel Commodore, New York, N. Y., will be sponsored by the National Industrial Conference Board.

In addition to the 17-nation review of international atomic energy progress and problems, the program will include discussions of the current outlook in atomic power costs, uses of atomic by-products in medicine, uses of radioisotopes in process industries, how to get "know-how" in atomic energy, public safety and power reactors, economic factors in locating reactors, legal problems, agricultural uses of radioisotopes, atomic energy planning by American and Canadian companies, uses of radioisotopes in metal and metal-fabricating industries, use of fission products, and research reactors and their uses.

Countries to be represented at the meeting include Argentina, Australia, Belgium, Brazil, Canada, Denmark, France, Great Britain, India, Italy, Mexico, The Netherlands, Norway, Spain, Sweden, Switzerland, and the Union of South Africa.

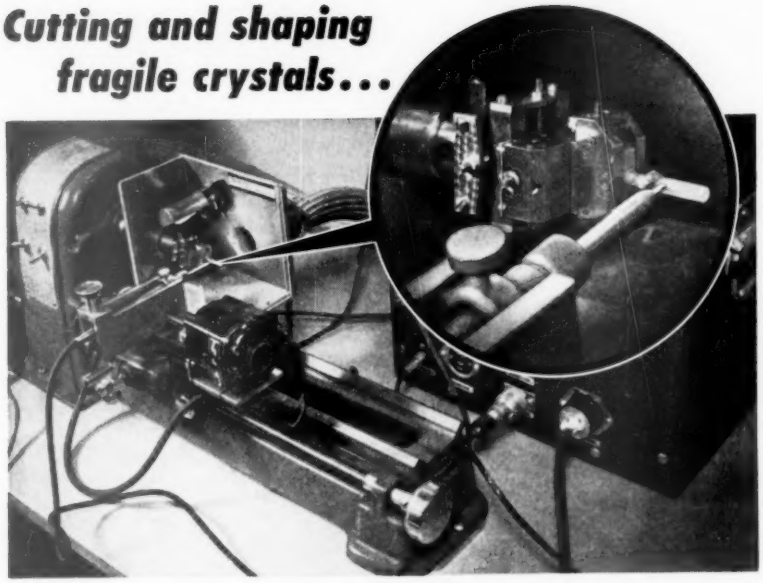
RAW MATERIALS

• **United States.** Four phosphate fertilizer plants are now extracting uranium economically. Blockson Chemical Co. was first; in the past year Texas City Chemical Co., International Minerals and Chemical Co., and Virginia-Carolina Chemical Co. have built plants. The latter three were built solely with private funds; AEC purchases uranium output under a firm-price contract.

• **Australia.** Discovery of a new 500 square mile uranium area, coupled with a new ore extraction process, will save the State of Australia over $10-million in uranium production costs.

Experimental drilling in the newly discovered area 75 miles northwest of known uranium deposits at Radium Hill indicates that it contains many millions of tons of ore. Plans are to

Cutting and shaping fragile crystals...



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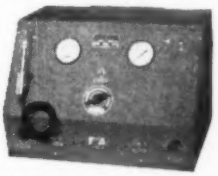
INDUSTRIAL "*AIRBRASIVE*" UNIT

The S.S.White "Airbrasive" Unit is opening-up vast, new approaches in the development of improved electronic components by providing a practical solution to many of the difficult "problem-jobs" encountered in producing these parts. Cutting spiral bands on film-type resistors, cutting germanium, accurately removing deposited surface coatings, and drilling thin sections of glass and other hard, brittle materials are but a few of the difficult jobs now made practical by this highly versatile, machine.

For example, exasperating difficulties had been encountered in cutting and shaping crystals for X-ray and neutron diffraction work. Ordinary cutting and grinding operations were prone to cause fracture. One laboratory applied the S.S.White "Airbrasive" Unit to this task and reported, "There is absolutely no other convenient way to do crystal-shaping for our work than by means of the Unit." The crystals are first manually cut into sections of roughly correct size with the "Airbrasive" Unit. Then, as illustrated, the rough crystal is mounted on a standard goniometer head and oriented optically or by X-ray. The goniometer head is placed on a small lathe, and the "Airbrasive" tool is mounted on a toolholder. Fragile materials have been successfully shaped into accurate cylinders with diameters to a fraction of a mm and lengths of 1.5 to 2 cm.

S.S.White engineers will be glad to conduct tests on any of your parts and will advise you as to the suitability of the "Airbrasive" Unit for your needs.



The "Airbrasive" Unit operates on 110 V, 60 cycle A.C. current. Any DRY inert cylinder gas can be used as a propellant.

WRITE FOR BULLETIN 5307 It contains complete facts and data on how the "Airbrasive" Unit operates and how it can be adapted to specific operations.

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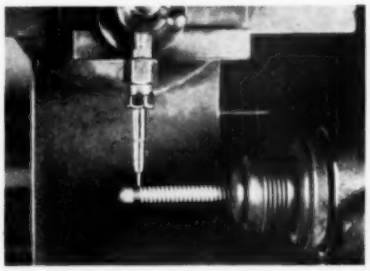
"AIRBRASIVE" NOTES FOR NUCLEAR ENGINEERS



Removing Deposited Surface Coatings

The S.S.White "Airbrasive" process provides a low-cost method of producing deposited carbon resistors. With the resistor mounted in a lathe, the "Airbrasive" stream can be set to cut accurate spiral bands along the length of the resistor body. Many companies are using this method today on an automatic set-up.

Cutting Germanium

The problem of cutting into wafer-thin crystals of germanium and other crystalline materials is greatly simplified by the "Airbrasive" process. The "Airbrasive" cutting action eliminates the shock, heat and vibration that are characteristic of other cutting methods.

Technical Literature

Several interesting articles on the use of the "Airbrasive" technique are available in reprint form.

Automatic Production Machine for Close-Tolerance Printed Resistors by Jack Bayha, Emerson Radio and Phonograph Corp., describes a three-station "Autobrader" for printed circuit production.

Method for Cutting and Shaping Fragile Crystals by Ray Pepinsky, Dept. of Physics, Penna. State College, describes the process of preparing crystals for neutron diffraction studies.

Write The S.S.White Industrial Division, Dept. 16, 10 East 40th Street, New York 16, New York.

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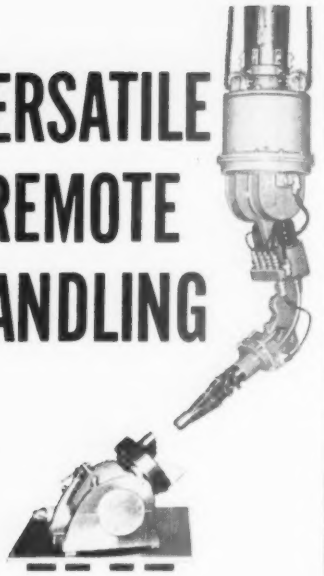
VERSATILE REMOTE HANDLING



A wide range of hazardous operations are performed safely with the new General Mills Remote Handling Manipulator. The unit offers unusual strength (can handle objects weighing as much as 750 pounds) and superb control (picks up eggs without cracking them).

Continuously variable power and speed controls are easily mastered and eliminate many of the restrictions found in hand-powered or position-controlled mechanisms.

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use it to supplement the Radium Hill supply.

The new ore treatment process involves flotation and resulted from 18 months' research in the South Australian Mines Department's research plant at Adelaide. Ore crushed into one-inch pieces is dropped into a tank containing a semi-liquid. Pieces containing a high percentage of uranium ore sink to the bottom. Only one-fifth the ore produced in the field need be transported to the processing plant. This will make it possible to reduce the cost of the processing plant at Port Pirie as much as 80% from original estimates of $17-million.

NEWSMAKERS

Charles D. Luke succeeds **James G. Beckerley** as Director of the Atomic Energy Commission's Office of Classification on Sept. 1. Since 1940, Dr. Luke has been professor and chairman of the department of chemical engineering at Syracuse University. From 1950–1952, he served as an AEC consultant, having previously been involved in fluorine and hydrocarbon research, uranium chemistry, pilot plant development and gaseous diffusion operations for the Manhattan Engineer District. Dr. Beckerley is resigning to return to private industry.

Arthur Roberts, University of Rochester physics professor, will serve as scientific liason officer in nuclear physics with the U. S. Office of Naval Research in Europe. He has been granted a year's leave of absence for this service in London. **Robert E. Marshak,** chairman of Rochester's physics department, returns in September from a year's lecturing in Europe under a Guggenheim fellowship.

Leonard I. Schiff, Stanford University physics professor, has been named as consulting editor of the International Series in Pure and Applied Physics. This textbook series is published by McGraw-Hill Book Co. G. P. Harnwell resigned the editorship when he accepted the presidency of the University of Pennsylvania.

Sylvan S. Cromer is now co-director of the aircraft nuclear propulsion project at Oak Ridge National Laboratory. He also is director of the aircraft reactor engineering division, formerly the aircraft nuclear propulsion division. Formerly, he was superintendent of the technical division of the Oak Ridge diffusion plant for Carbide and Carbon Chemicals Co.

MEETINGS

September 7–10: Nuclear Science in Engineering Education; Evanston, Ill. A 33-member panel discussed the present status of nuclear engineering, current curricula at several universities, and industrial needs for engineers at Columbia University last April. Members of the panel will lead this four-day conference open to physics and engineering teachers. Reservation blanks are available from R. L. Young, M. E. Dept., Technological Institute, Northwestern University, Evanston. Co-sponsors of the conference are the American Society for Engineering Education, American Institute of Physics, the National Science Foundation, and Columbia and Northwestern Universities.

September 13–15: Analytical Instrument Clinic; Philadelphia, Pa. (NU, July '54, p. 96).

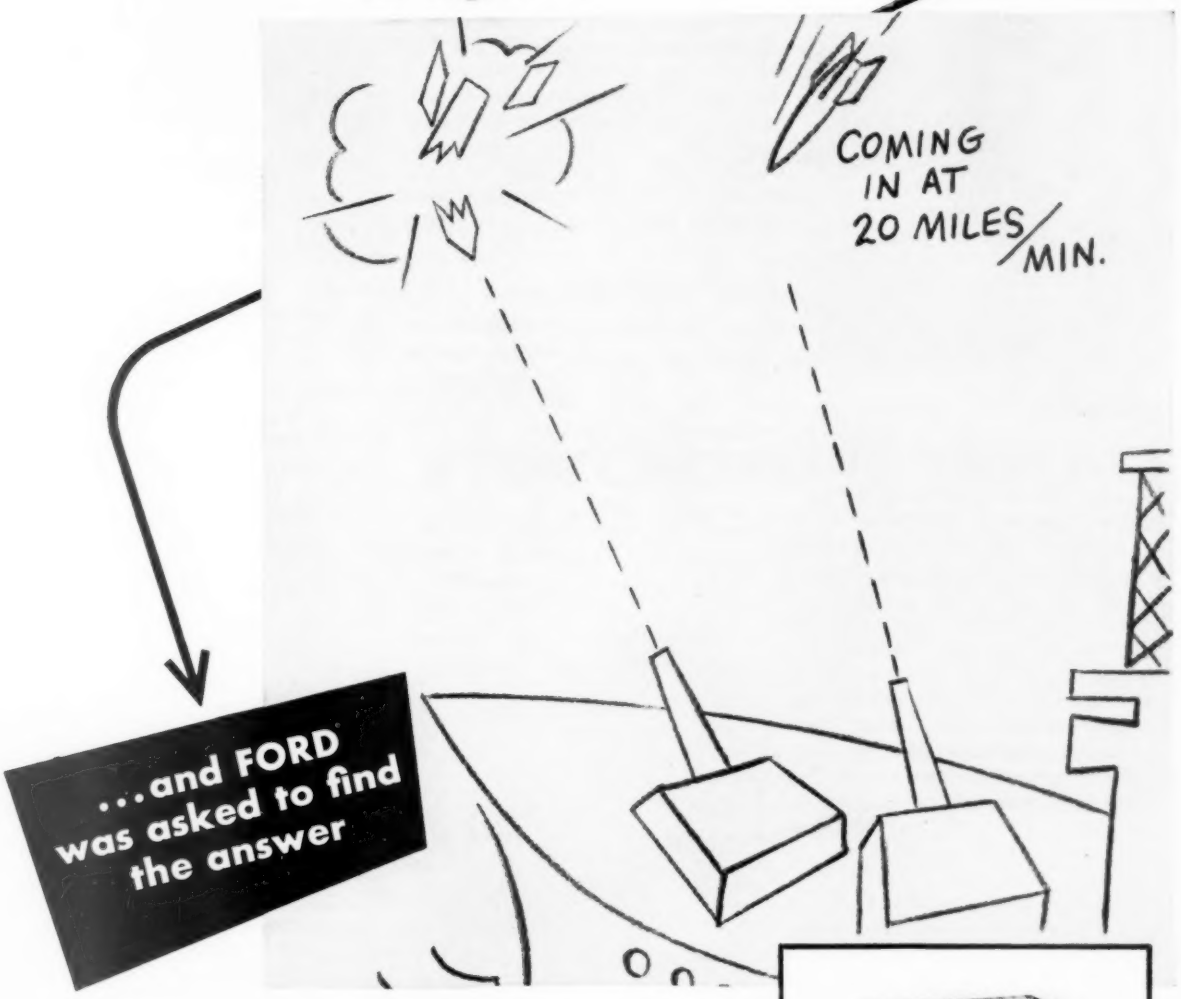
October 6, 7: Institute of Radio Engineers' Conference on Nuclear Science; Chicago, Ill. (NU, May '54, p. 79). Invited speakers include A. M. Weinberg, Oak Ridge National Laboratory; W. M. Brobeck, University of California Radiation Laboratory; L. B. Borst, University of Utah; Robert Vestergaard, Sweden; J. Walker, AERE, England; and W. B. Lewis, Chalk River, Canada.

October 6–8: Symposium on Applications of Radioactivity; Boston, Mass. Fundamentals of radioactivity, radiation-induced polymerization, and industrial applications of radioactivity will be discussed to acquaint members of the plastics and rubber industries with uses of radioactivity. Additional information can be obtained from the sponsor; Symposium committee, Technical division, Tracerlab, Inc., 130 High St., Boston 10, Mass.

November 3–5: Twelfth Annual Pittsburgh Diffraction Conference; Mellon Institute, Pittsburgh, Pa. Sessions will cover instrumentation and methods, neutron diffraction, small-angle scattering, metals, and silicates and related structures. Titles should be submitted to G. A. Jeffrey, University of Pittsburgh, before Sept. 1. For information, write to P. K. Koh, Allegheny Ludlum Research Laboratories, Alabama Ave., Brackenridge, Pa.

April 27–29, 1955: Conference on Nuclear Engineering, Los Angeles, Calif. (NU, July '54, p. 86). Original notice was in error; the conference will be in Los Angeles, not Berkeley.

HOW TO HIT A SUPERSONIC MISSILE in flight



An enemy guided missile comes winging towards our task force . . . at speeds of up to 20 miles a minute. What kind of computer can predict and compute the necessary data fast enough to shoot down the missile . . . and be reliable every time? That was the problem posed to Ford Instrument Company engineers . . . and in cooperation with the Navy, they found the answer. Compact equipment, housed in easy-to-service units . . . that stand at the front line of our defense.

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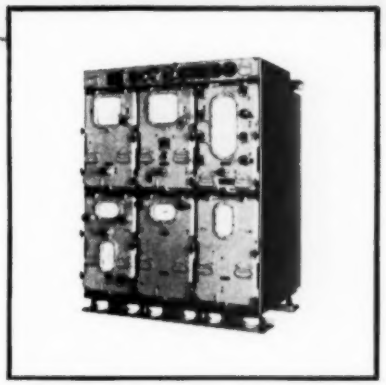

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Manipulator

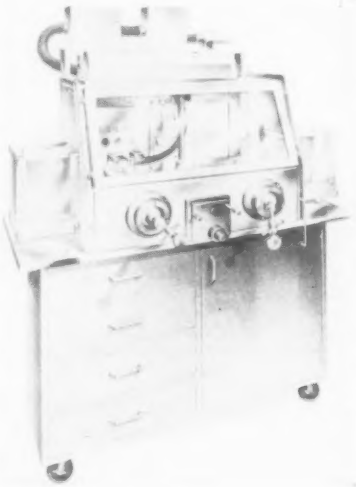
Model 8 master-slave manipulator effectively handles loads of 10–15 lbs in any operation; up to 60 lbs can be handled in a straight lift with an auxiliary lifting hook. The sensitive manipulator mechanism permits the operator to duplicate any manual operation on the slave end from the master end behind the barrier. A canting mechanism is used that enables the operator to bring the specimen up to the viewing window without backing away. The mechanism automatically raises the slave end to the horizontal so that the manipulator arm can be removed or repositioned. The useful working area for a pair of arms inside a cell is approximately 5 ft deep and 8 ft wide at a table height of 40 in. from the floor. It can reach a depth of 8 ft from the barrier wall at a working height of 5½ ft above floor level. With proper cell design radiation sources in the multikilocurie range may be handled with safety. *Central Research Laboratories, Inc., Red Wing, Minn.* (P-1)

Pressure Syringe

This shielded pressure syringe, capable of delivering radioactive solutions up to 50 mc, utilizes a stainless-steel piston and glass barrel; "O" ring seal in moving piston prevents back leak. Ratchet device prevents the syringe from backing up while injecting under pressure into tumor masses. Capacity of the syringe is 5 cm³. Injection manipulation is one-handed, like a gun. Syringe is said to have been leak-proof under 200 lb/in.² Gun accommodates needles smaller than 26 gage. *Jewish Memorial Hospital, Broadway and 196th St., New York 34, N. Y.* (P-2)

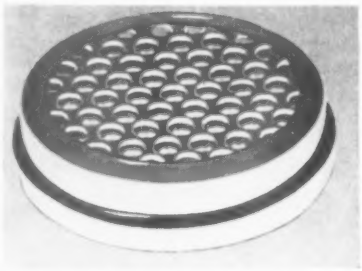
High-Vacuum Valve

The series 1200 valve is designed for high-vacuum service in the micron range. By omitting the needle-point, the valves can be obtained as globe valves. The stem-seal used with these valves can also be used on other lines of automatic valves, such as diaphragm and cylinder types. *Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.* (P-3)



Remote Control

The CBR remote control is particularly useful where the radiation level suggests remote controls for personnel protection. Interior accessories include stirrer, recessed centrifuge, rotating reagent rack, etc. Mechanical tongs are operated from the exterior of the unit for additional facility. External lead caves are available for use with beta and gamma activity where an unshielded unit is inadequate. *Kewaunee Mfg. Co., Adrian, Mich.* (P-4)

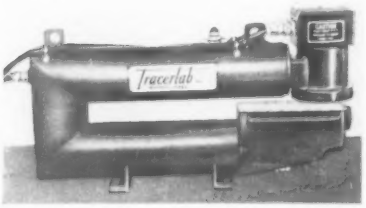


Alpha, Beta Detectors

Two light-tight scintillation counters are available, one to detect alpha particles but not other radiations, and another that detects beta particles but is relatively insensitive to gamma rays and neutrons. Alpha detector contains a closely packed monolayer of alpha-sensitive phosphor, covered with aluminum foil. The foil is transparent to alpha particles but not to light. Beta detector is made of a half-millimeter-thick slice of a single crystal of stilbene covered by polished aluminum foil. Both detectors are hermetically sealed against an ultraviolet transmitting glass to form a light-tight assembly that is interchangeable with other counters. *National Radiac, Inc., Newark, N. J.* (P-5)

Radiochemicals

Several carbon-14 labeled compounds are available in standard 0.1-millicurie packages. These include sodium bicarbonate, carbonate, and acetate and glycine. *Bio-Rad Laboratories, 800 Delaware St., Berkeley, Calif.* (P-6)



Cesium Beta Gage

The BG-5 light materials gage permits sensitive control of sheet weight. The gage utilizes a radioactive source of cesium-137, a low-energy isotope with a 33-yr half-life, suiting it to long-life gaging of light materials. Its 3 mg/cm² full-scale sensitivity is equivalent

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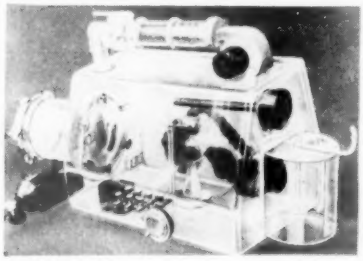
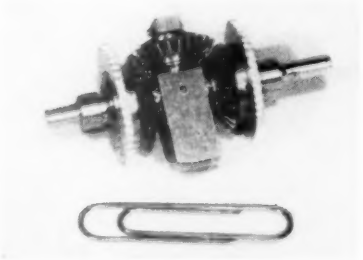
to a basic weight change of only 20 lbs/3,000 ft² of paper or thickness change of 1.2 mils of a plastic film, such as Saran. Gage may be obtained with "C" frames having a variety of depths and all-angle scanning mounts to provide across-the-sheet weight profiles. *Tracerlab, Inc., 130 High St., Boston 10, Mass.* (P-7)



Control Hood

Group model No. Len-13 control hood offers protection from radioactive isotopes and dusts of alpha and beta energies and low-energy gamma rays. Integrated design of the units permits atmospheric controls such as rust control, relative humidity and temperature, maintaining inert gas or dust-free atmosphere. Equipment employs a humidistat sensitive to change of relative humidity as low as 2%. Control hood is made of clear plastic material that is chemically inert and has complete stability at 450° F. *Paul Lennard & Co., 671 Bergen St., Brooklyn 38, N. Y.* (P-8)



Computing Differential

This differential was designed to mechanically add and subtract with high accuracy and operate over a wide environmental range. The unit weighs less than one oz, performs in a working circle of 1-in. diam., and has a breakaway torque rating, at no load, of 0.01 oz-in. *Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.* (P-9)

Scaler

The model 161A scaler is designed for use with G-M or scintillation counters. The instrument is capable of counting up to 120,000 cpm with only 1% coincidence loss. It is a complete unit requiring only a detector and timer. Unit utilizes scaling factor of 256, stabilized high-voltage supply for the detector and six-digit register. *Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (P-10)

Expanded-Scale Voltmeter

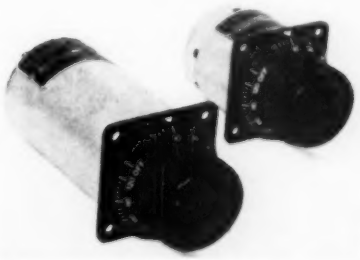
The model 101 a-c voltmeter features both scale expansion and recording over the 100–500 volt range and covers the range in 39 10-volt full-scale steps. True rms readings are obtained with accuracies better than ±0.25% of input voltage; frequency response is uniform between 50 and 2,000 cycles. Built-in recorder connections are provided for recording line-voltage fluctuations with a 1-ma d-c recorder. *Beckman Instruments, Inc., Arga Div., South Pasadena, Calif.* (P-11)

Scintillation Phosphors

Liquid phosphors NE201 and plastic phosphors NE101 are available for scintillation counters. The liquid phosphors are supplied in sealed, flat-bottomed, cylindrical glass cells in a variety of sizes. Compared with anthracene crystal of the same weight, NE201 has a counting rate of 95%, pulse height of 75% and a decay constant of 2×10^{-9} sec. They are provided with an MgO reflector and are protected by a thin aluminum spinning. Plastic phosphors are available in a variety of diameters and lengths. They are composed of 91% carbon and 9% hydrogen and have a density of 1.028. Compared with anthracene crystal of the same weight, NE101 has 90% counting rate, 50% pulse height and decay constant of 4×10^{-9} sec. *Nuclear Enterprises Ltd., 1750 Pembina Highway, Winnipeg, Canada.* (P-12)

Potentiometer

The model HF1 portable potentiometer was designed for field and laboratory use with a range of 0–100 mv and has an accuracy of 0.1 mv plus 0.15%. The total resistance of the measuring slide-wire is 100 ohms and the smallest division on the dial is 0.1 mv. *Williamson Development Co., 317 Main St., W. Concord, Mass.* (P-13)



Sequence Timer And Limiter

The Types B-9A and B-10A Intervalometers furnish a 28-volt, d-c, 3-ampere inductive pulse of 0.25-sec duration at adjustable time intervals. The time interval between pulses is determined by the dial setting, and is accurate to within ±10 msec over a supply range of 24–29 volts, d-c. Each model is provided with two interchangeable time-interval scales providing, in all, 4 ranges of 12, 24, 60

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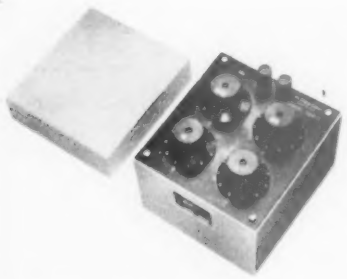
and 120 sec in 0.1, 0.2, 0.5 and 1 sec increments, respectively. The CN-1A1 count limiter may be used with the Intervalometer as a pulse counter and limiter for stopping the Intervalometer at the desired number of pulses, from 1 to 120, as set on its dial. Two count limiters can be connected together to control 14,400 pulses. Any number of units can be combined for a variety of preset programs. *Abrams Instrument Corp., 606 E. Shiawassee St., Lansing, Mich.* (P-14)

Geigerscope

The Geigerscope was developed for inexpensive, visual detection of alpha rays. The specimen's rays bombard a scintillation phosphor-coated screen to produce a series of light flashes. The frequency of the flashing determines the amount of the specimen's radioactivity. *Ken Research, Inc., River Edge, N. J.* (P-15)



Decade Resistance Box

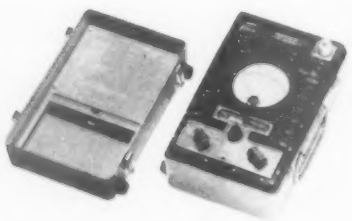
This decade resistance box is supplied in 27 models to cover a total range from 1 ohm to 110 megohms. Each decade includes 10 precision wire-wound resistors made of an alloy having a negligible temperature coefficient. Accuracy is said to be within $\pm 0.1\%$. Units employ positive audible detent switches. *The Winslow Co., 9 Liberty St., Newark 2, N. J.* (P-16)

Respirator Filter

The Super Micro-Toxisol Respirator removes airborne radioactive matter and other toxic dust, mist and fumes and protects against spores, viruses, bacteria and fungi. The filter is said to protect industrial and laboratory workers against particles down to the 0.3 micron size with 99.99% efficiency. Respirator face pieces take two filters, providing a total filtering area of 90 in^2. The rim of the lightweight-aluminum cartridge is made so as to insure positive sealing against a rubber gasket. *American Optical Co., Southbridge, Mass.* (P-17)

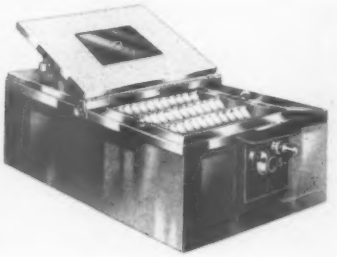
Computer Power Supply

The type C d-c power supply is a magnetically-regulated unit designed for computer work. The internal impedance is low and decreases with increasing load frequency. Dynamic regulation is said to be better than 0.1% for a step change of a-c line voltage from 95 to 135 volts, and better than 0.1% for line-frequency variations from 57 to 63 cps. For output-load variations from zero to full load, static regulation is better than 0.15%, and dynamic regulation is better than 0.2% for a step change of 20% in d-c load current. Ripple is less than 0.2% rms and can be reduced to 0.01% if required. Units are supplied in ratings ranging from 1.5 to 500 volts and 1 to 100 amperes d-c output. *Magnetic Research Corp., 318 Kansas St., El Segundo, Calif.* (P-18)



Volt-Ohm Microammeter

The model PL 1004 Multimeter, made for the military as the TS-352B/U, is a waterproof volt-ohm-microammeter. It is claimed that this multimeter can be immersed in water without affecting its accuracy. It is adaptable for a-c and d-c measurements of electronic and electrical circuit elements. *Phaostron Co., 151 Pasadena Ave., South Pasadena, California.* (P-19)



Constant-Temperature Bath

This constant-temperature bath, for inspissating work, is supplied with eight slanting racks, each rack having a capacity of ten culture tubes. It has triple-wall construction, with a water jacket for maintaining uniform temperature throughout, and is suitable for coagulations at 60°, 70°, 80° and 90° C. Working temperature range is up to 100° C. Radiant-wall-type heating is controlled by means of a sealed hydraulic thermostat. Two glass observation windows permit observation when cover is lifted without disturbing temperature uniformity. *Chicago Surgical & Electrical Co., 217 N. Desplaines St., Chicago 6, Ill.* (P-20)

Variable Time Delay

The type 303 variable time delay is suitable for delaying pulses or measuring small time intervals. Rise time is <7% of the time delay and over-

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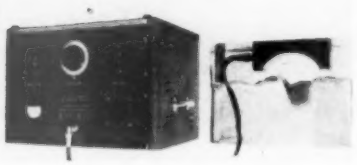
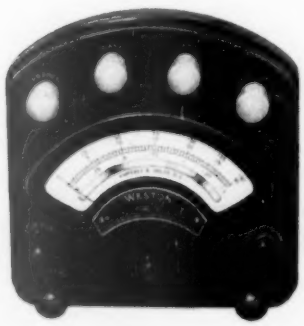
shoot is <2%. The instrument consists of an input and output amplifier and continuously variable delay line available in ten ranges from 0–0.05 μsec to 0–0.8 μsec. Input impedance is 1 megohm shunted with 20 μμf; output impedance is 1 megohm shunted with 15 μμf. Both amplifier stages have 15-Mc bandwidth and 10-volt peak-to-peak maximum signal level. Accuracy can be maintained within ±1% after calibration. *Advance Electronics Co., Inc., 451 Highland Ave., Passaic, N. J.* (P-21)



Ultrasonic Cleaner

The model 500 ultrasonic power generator is designed for accelerating cleaning and degreasing small parts and metal objects, such as strip, wire and tubing, as well as complex components. It functions by activating a cleaning solvent with a low voltage focused ceramic transducer. Installation in conventional vapor-degreasing systems is facilitated by long cables from power unit. *Branson Instruments, Inc., Stamford, Conn.* (P-22)



Miniature D-C Meters

The model 281 miniature portable d-c electric meters employ the Weston core-magnet mechanism; self-shielding is such that the magnetic field of a conductor carrying 15,000 amperes, 3 ft from the instrument, is said to cause a temporary error in indication of <1%. The large moving coil employed gives improved performance with a high torque-to-weight ratio. Scales are hand calibrated; mirror and

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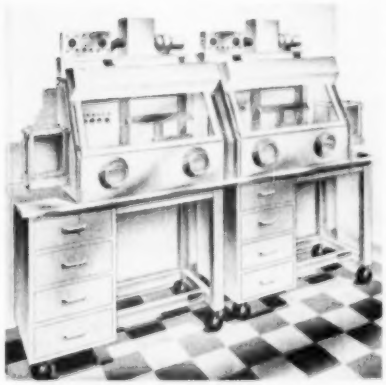

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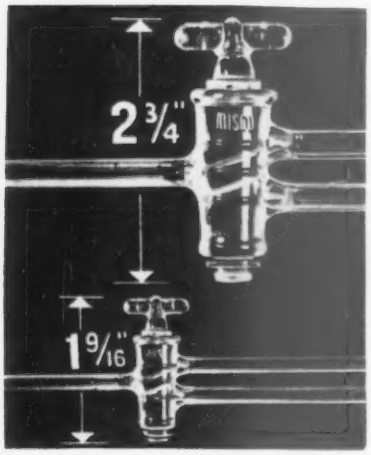
knife-edge pointers are combined to eliminate parallax error. Meters are supplied in a variety of ranges in single and multirange voltmeters, ammeters and volt-ammeters. *Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.* (P-23)

High Voltage Supply

The model 515 high voltage supply delivers 500–1,500 volts, d-c, with currents of 2 ma up to 1,000 volts and 1 ma above 1,000 volts; polarity is positive or negative. Stability is said to be 0.01% drift over several hours and less than 0.02%/day. Regulation is claimed to be better than 0.01% change for line voltage variations between 70 and 140 volts and loads of 0–1 ma. Output ripple is <10 mv. *Radiation Instrument Co., Box 733, Silver Spring, Md.* (P-24)



Micro Stopcocks

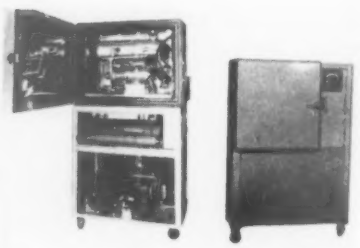
These stopcocks were designed for micro operation and are available in a variety of shapes to make apparatus more compact, reduce dead space and improve appearance. Plugs are precision ground and interchangeable; holes drilled through plugs have $\frac{1}{2}$, $\frac{3}{4}$ and 1 mm bore diameter. *Microchemical Specialties Co., 1834 University Ave., Berkeley 3, Calif.* (P-25)

Miniature Generator

The type 44A generator, recommended for instrument indicating and similar applications, is rated for continuous duty with an output frequency of 20 cps and a maximum of 3% harmonic distortion. Output is linear with speed; unit develops 33 volts of 2-phase a-c at 4,500 rpm. Internal winding resistance is 30k/phase. *Dalmotor Co., 1356 Clay St., Santa Clara, Calif.* (P-26)

Infrared Lamp

These fused translucent quartz infrared lamps are made in two sizes, 500 and 1,000 watts, for 115 and 230-volt supplies, respectively. The lamps develop high energy concentrations (100 watts per "lighted in." of tube length) and produce full radiation without a warm-up period. They supply visible light as well as infrared radiation and can withstand high temperatures with wide variations. The lamps have a rated life of more than 5,000 hr. *General Electric Co., Nela Park, Cleveland 12, Ohio.* (P-27)

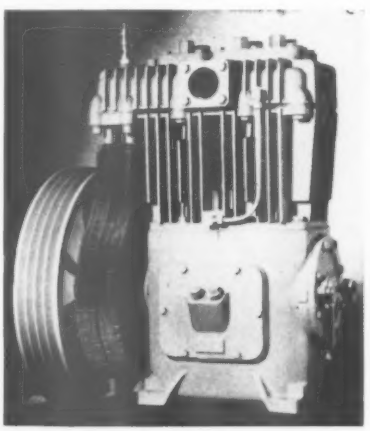


Environmental Chambers

This series of portable environmental test chambers provide dry-chamber working areas of 1–64 ft³; temperatures between +250° F to −120° F can be held, controlled and recorded. The same series is also available as a temperature-controlled liquid chiller that operates at any point from +500° F to −120° F with an accuracy said to meet any specific requirement. These portable models have a heat removal capacity of 300–50,000 btu/hr. *Conrad, Inc., Holland, Mich.* (P-28)

Plug-In Attenuators

The 690 series of plug-in attenuation networks have a plug-in provision for adjusting input and output impedances. They are available in T or balanced-H circuits with a range of 110 db in 1-db steps on the 2-dial series, or a range of 111 db in 0.1-db steps on the 3-dial series. A special card-type, noninductive winding is used, giving a frequency range of zero to 50 kc. Resistor units are calibrated to ±1% accuracy and operate at a 20-db (0.6 watt) maximum input level. *Daven Co., Dept. SX, 191 Central Ave., Newark, N. J.* (P-29)



Compressors

Compressor models 255 and 350 are designed for applications requiring continuous pressures of 100 and 200 lb/in², respectively. The 350 can deliver intermittant pressures up to 350 lb/in². *Quincy Compressor Co., Quincy, Ill.* (P-30)

Power Resistors

The types PW-7 and PW-10 high-temperature resistors are designed for dissipation of 7 or 10 watts or less. Wire elements are uniformly and

tightly wound on glass fiber cores with axial leads. These element-lead assemblies are sealed into a ceramic case with an IRC cement to provide a mechanical protective bond. Type PW-7 is available from 0.51 to 5,100 ohms, and type PW-10 from 1 to 8,200 ohms, both providing ±5% and ±10% tolerances. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (P-31)

Ohmmeter, Leakage Tester

The model C-6 resistance meter, by means of a quick-charge switch and charge-adjust control, can preset an acceptable value of leakage resistance into the meter and determine immediately whether or not the capacitor meets the requirement. Either 50 or 500 volts, d-c, may be used in measuring resistance in the megohm range. The 500-volt test meets the JAN and MIL specifications for insulation testing, while the 50 volts is available for testing capacitor leakage. The range from zero ohms to 10 million megohms is covered in ten decade steps; accuracy is 3% of full-scale deflection. *Southwestern Industrial Electronics Co., 2831 Post Oak Rd., Houston 19, Texas.* (P-32)

Colloid Mill

The TV 45 Ultra-Turrax colloid mill is used to make suspensions, stable emulsions, and colloidal solutions. The efficiency of the mill is due to the complex action of high-frequency shock and impact effects as well as the cavitation produced in the supersonic frequency range by the simultaneous action of high-frequency hydrodynamic potential gradients and effective turbulence occurring inside the vortex chamber of the colloid mill itself. Dispersion is in the order of a fraction of a micron. According to depth of immersion (up to 25 cm), the instru-

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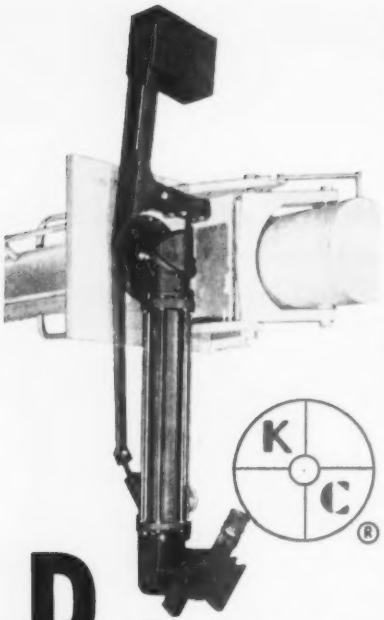

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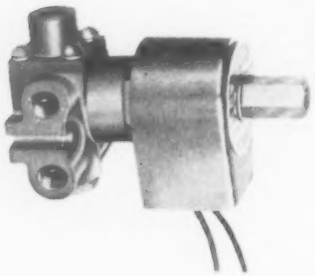
ment operates with or without the formation of froth; wave baffles are not required because no "funnels" are formed. Vortex chamber has 45-mm diameter. *Chemical Products Div., Cartrite International, Inc., 535 Fifth Ave., New York 17, N. Y.* (P-33)



Solenoid Valve

The Bulletin 8345 valves are designed for controlling small double-acting cylinders not larger than 4 in. in diameter. They are used for air, water, light oil, and noncorrosive gases and liquids. The valves are available for 115 volts, a-c/d-c, and 230 volts, a-c, operation. Permissible pressure range is 10–125 lb for a-c and up to 50 lb for d-c operation. Solenoids are available as standard, watertight and explosion-proof. Units operate at temperatures up to 212° F. *Automatic Switch Co., Orange, N. J.* (P-34)

Pulse Generator

The type 1217-A pulse generator delivers continuously adjustable pulse durations from 0.2 to 60,000 μsec and is powered by the type 1203-A power supply. A self-contained oscillator drives the output at 12 fixed frequencies from 30 cycles to 100 kc. Pulse rise time is said to be less than 0.05 μsec and the fall time about 0.15 μsec. Open-circuit output voltage is 20 volts for pulses of either polarity; internal output impedance is about 200 and 1,500 ohms for the positive and negative pulses, respectively. *General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.* (P-35)

Cathode-Ray Oscillograph

The type 323 cathode-ray oscillograph is designed for measurements of time and amplitude over the range of general laboratory applications. The direct-coupled, 10-Mc (3 db down) vertical amplifier enables display of very-low-frequency phenomena and high-speed pulses, together with their d-c level. Sweeps are directly calibrated by means of a front-panel dial; recalibration is accomplished with an internally supplied time standard by adjusting one control. The sweep range is 1 sec to 0.1 μsec per inch; any 2-in. portion of the 4-in. trace can be expanded. *Allen B. Dumont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N. J.* (P-36)

Microphotometer

The console model Comparator-Microphotometer is designed as a desk-height cabinet with foot control for drive and left-hand positioning of panel switches to free the right hand for making notes and plate marking. Sensitivity yields full-scale deflection for effective slit size of 1 micron × 0.7 mm (700μ²) or better. Reproducibil-

ity exceeds 0.25% while speed is sufficient to measure 4 lines/min or more. Scattered light does not exceed 0.7% and linearity is held within 3%. An 18 × 9 mm area is projected onto the 11 × 11 in. translucent screen at a magnification of 15×; spectrum is visible at all times during the scanning cycle. *Jarrell-Ash Co., Newtonville, Mass.* (P-37)

Demineralizer

The model BD-2 pressure demineralizer delivers water under 5- to 25-gal/hr pressure so that it can be piped to any desired point. Demineralizer is wall mounted and connects to any water line. It is a nonregenerative unit that employs a replaceable resin cartridge. No heat or cooling water is required. *Barnstead Still & Sterilizer Co., Lanesville Terrace, Forest Hills, Boston 31, Mass.* (P-38)

Optical Pyrometer

The micro-optical pyrometer can measure temperatures over 700° C and tar-

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The coil form shown in this RCA-Victor precision tank coil is injection-molded of MYCALEX 410 glass-bonded mica insulation. The coil, operated at approximately 1000 rpm, is subject to high start and stop stresses. The winding contacts a travelling disc and operates at high potential and high frequency. MYCALEX was selected for this application after careful evaluation. The extreme dimensional accuracy, attainable with MYCALEX glass-bonded mica – the unique ceramoplastic – insures perfect contacting and at the same time eliminates balance problems. High dimensional accuracy also affords absolute uniformity of parts, facilitating assembly and replacement. The excellent dielectric properties of MYCALEX insure efficient electrical performance.

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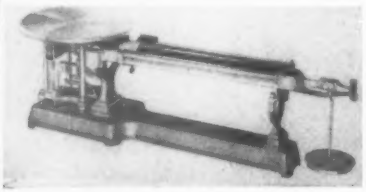
gets less than 0.001 in. in diameter. By means of supplementary lenses, focal distances can vary from 5 in. to infinity. Mountings on table-top and floor-type tripods are available. The optical system includes a microscope-type ocular providing a 20-power magnification. *Pyrometer Instrument Co., Inc., Bergenfield, N. J.* (P-39)

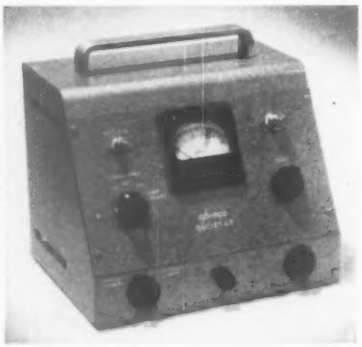


Solution Balance

This heavy-duty solution balance, for laboratory weighing of solutions, powders, grains, animals, etc., has an 11-in. weighing platform. The balance is available in metric, avoirdupois or both standards. *Ohaus Scale Corp., 1050 Commerce Ave., Union, N. J.* (P-40)

Water Hardness Test

The Speedy-Kit is said to enable field tests of water hardness to one grain/gal (17.1 parts/million) in one minute of testing time. This kit, based on the Schwarzenbach method of testing water, is comprised of two bottles with eyedropper tops and one glass vial. Reagents are sufficient for 50–100 tests. *Calgon, Inc. or Hagan Corp., Box 1346, Pittsburgh 35, Pa.* (P-41)



Regulated Power Supply

The Duostat power supply provides both constant-current and constant-voltage operation. Powered by a standard 115-volt a-c source, supply is capable of delivering currents of 5–50 ma, regulated to within ±2% at voltages ranging from 100 to 500 volts. In its constant-voltage mode of operation, the unit is self-regulated to within ±1% from 160 to 500 volts, over a load range of 0–50 ma. Output is relatively unaffected by line voltage changes between 105 and 125 volts. *Specialized Instruments Corp., 668 O'Neill Ave., Belmont, Calif.* (P-42)

Noninductive Resistors

This line of K-F precision resistors is available in values of 0.1 ohm to 1 megohm with accuracies of 1, 0.5 and 0.1%. Wound noninductively on non-hygroscopic ceramic bobbins and impregnated for moisture protection, these units exhibit low thermal emf and a temperature coefficient of 0.000025 ohms/° C. Nine sizes are supplied ranging in power capability from $\frac{1}{4}$ to 1 watt. Values under 800 ohms are wound with Manganin wire; values over 800 ohms, in Evanohm. *K-F Development Co., 2683 Spring St., Redwood City, Calif.* (P-43)

D-C Amplifier

The type 2HLA-3 d-c indicating amplifier, for minute voltages and currents, measures signals as low as 2×10^{-15} watt. The amplifier employs a second-harmonic magnetic converter as input stage to change d-c signals to a-c, eliminating the need for mechanical choppers. Unit has linear amplification (±1%) on all scales and long-term drift of less than 10 μv. Frequency response is flat from zero to 20 cps and gain is independent of line variations from 105 to 125 volts. Power output can drive most recorders. *Dorlcam Corp., 1400 Soldiers Field Rd., Boston 35, Mass.* (P-44)

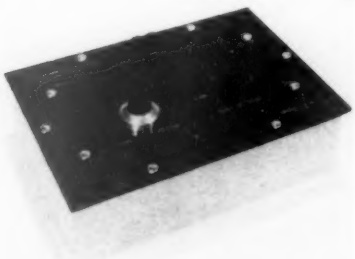
Power Supply

The Regatron series power supply provides a variable d-c voltage standard, regulated power supply and research voltage source with small signal modulation. D-c supply voltage is 0–600

volts, adjustable with a ten-turn potentiometer calibrated within 0.25%. The currents available with this series are 0–600 ma or 0–1,000 ma. Regulation is within 0.05%. *Electronic Measurements, Inc., Lewis St. and Maple Ave., Eatontown, N. J.* (P-45)

Water Flow Control

The Mesurflo control automatically compensates for surges in line pressure and maintains a set flow rate. Waterflow control is preset to deliver one constant rate between 0.2 and 14 gal/min; accuracy is 10% within the range of 15–150 lb in^2. Flow controls are available in $^1/_4$-, $^3/_8$- and $^3/_4$-in. pipe sizes. *Hays Mfg. Co., 816 W. 12th St., Erie, Pa.* (P-46)



A-C Voltage Standard

The model VRS-AC10 tubeless a-c voltage standard was designed for direct checking and calibrating of vacuum-tube voltmeters and for indirect checking of power meters. The instrument has a range from 1 mv to 10 volts in three steps, with an accuracy within 0.25%. The unit is recommended for an output loading of 1 megohm or higher; output may be short-circuited without damaging the instrument. *Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn.* (P-47)

Refrigerant

"Freon-13" monochlorotrifluoromethane is a nonflammable and nonexplosive refrigerant designed for systems producing temperatures in the range of −70° to −150° F. Immediate applications are in metal treatment, chemical processing and testing work. Freon-13 is adaptable to compact, economical hermetic-type compressors, and is

The illustration shows the N550 Scintillation Counter in use with an Ekco N530 Automatic Scaler.

EKCO type N550

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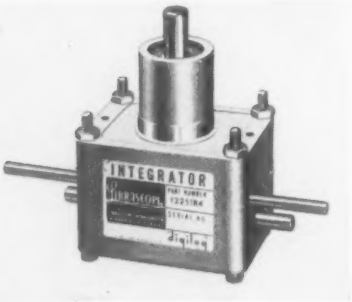
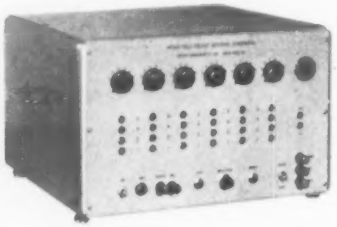
noncorrosive with metals and other conventional refrigeration components. *E. I. du Pont de Nemours & Co., Wilmington, Del.* (P-48)



Integrator

This ball and disk integrator is used for totalizing, rate determination, differential analyzers, or as a closed-loop mechanical servo element or precision variable-speed drive. A permanent lubrication device is said to increase life of the unit. *Librascope, Inc., 1607 Flower St., Glendale, Calif.* (P-49)

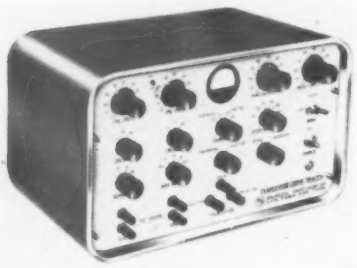


Interval Generator

The model 564 preset interval generator generates and measures time intervals and delays from 1 μsec to 1 sec. As generator, desired interval or delay is selected by means of six 10-position switches, one for each digit of the delay in μsec. To measure a time interval, the instrument counts pulses produced by a 1-Mc temperature-controlled crystal oscillator. Neon lamps give six-digit readings directly in μsec. Resetting is manual or automatic; with automatic resetting, instrument recycles itself to produce trains of pulses. *Potter Instrument Co., Inc., 115 Cutter Mill Rd., Great Neck, N. Y.* (P-50)

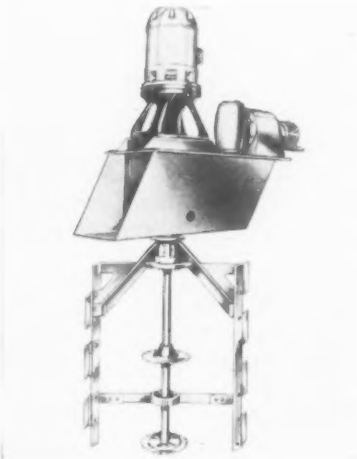
Self-Cleaning Air Filter

The Cyclo-Filter is an automatic, self-cleaning dust collector. Designed for heavy-duty work, it handles quantities of all types of dust, including abrasive and fibrous materials for long periods, while maintaining constant volume and uniform air flow. Approximately 75–95% of the dust is removed by cyclonic action, while the remaining particles are taken out through a series of cloth filter tubes. Reverse air jet cleans dust off these tubes and deposits it in dust container. Units range in capacity from 400 ft³/ min to 5,000 ft³/ min. All units are approximately 4 ft in diameter and require 11–15 ft headroom. *Torit Mfg. Co., 271 Walnut St., St. Paul 2, Minn.* (P-51)



Transistor Curve Tracer

This transistor curve tracer is a completely automatic instrument capable of measuring all types of transistors. Measurements are made by displaying the entire family of curves on a cathode-ray tube and are said to be accurate to within 3%, independent of scope drift or calibration. *Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y.* (P-52)



Combined-Speed Dissolver

This duplex-drive dissolver, designed for difficult solution, dispersion or suspension problems, combines the speed of the ultrafast dissolver with slow-speed, paddle-type agitation. Drive shaft of the high-speed unit runs

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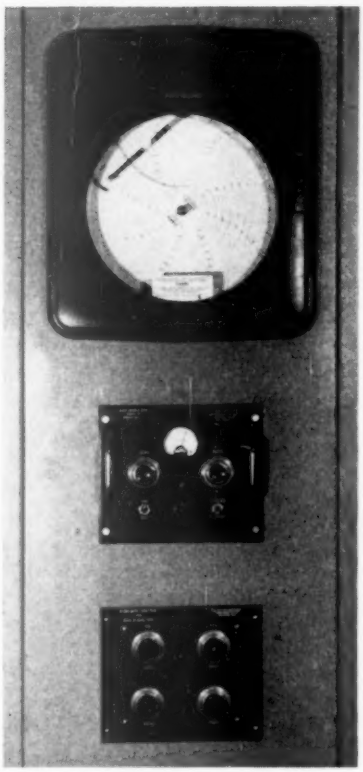
through the hollow, slow-speed drive; slow speed attachment can be designed to scrape the sides of the tank or as an agitator to run in either direction. The slow-speed agitator can also be used to hold a batch under gentle agitation, after preparation with the ultra-fast mixer, while waiting for future use. The duplex dissolver is available in sizes of 100–1,000 gal. *Cowles Co., Inc., Cayuga, N. Y.* (P-53)

Germanium Diode

Types CK739 and CK742 are the first two types in a new line of bonded germanium diodes having a high ratio of back-to-forward resistance, a characteristic desirable for computer use. These types are characterized by forward resistances of 10 ohms or less at one volt, and back resistances of several megohms at negative voltages as great as 125 volts for the CK742, and 62.5 volts for the CK739. *Raytheon Mfg. Co., 55 Chapel St., Newton 58, Mass.* (P-54)



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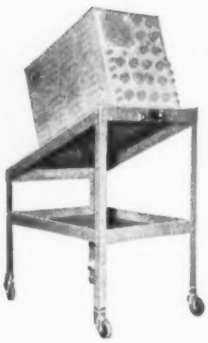

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Indicating Meter-Relays

The models 255 and 355 contact meter-relays, which are ruggedized and sealed units, comply with government specifications for both indicating meters and relays. The units are D'Arsonval instruments made in the usual a-c and d-c ranges. These meter-relays utilize platinum-iridium contacts that are claimed to be able to make and break 15,000,000 times before wearing out. These contacts are normally used at 5–25 ma, d-c, at 75–125 volts. The contacts can be made to close at the upper limit, lower limit or both, and can be supplied fixed or adjustable. *Assembly Products, Inc., Box 191, Chagrin Falls, Ohio.* (P-56)

Microvolt Generator

This generator delivers d-c and 60-cycle a-c voltages from 1 μv to 1 volt with a self-contained supply. An audio generator can be used to obtain frequencies other than 60 cycles. A constant 90-ohm input impedance attenuator, made up of 1% components, is used to adjust the 1-volt input to the required value. Output is isolated from ground and unit is completely shielded. *Scientific Specialties Corp., Boston 35, Mass.* (P-57)

Correction

The Jordan Electronic Mfg. Co. model AGB-10-SR beta-gamma survey instrument was incorrectly described in the June issue to have a range of

0.01 mr/hr to 10,000 mr/hr. The correct range is 0.01 mr/hr to 10,000 r/hr.

INDUSTRY NOTES

▶**R. S. Landauer, Jr. & Co.,** 118 Nanti St., Park Forest, Ill., provides a personnel-monitoring system for exposure to medical and industrial X-ray equipment and β- and γ-emitting isotopes. Three-absorber badge covers 30-kev to 5-Mev X- and γ-rays and β-rays above 400 kev. Quantitative coverage is provided for 0.05–500 r of high-energy and 0.02–100 r of low-energy radiation. Badge is retained and film-packet inserts are sent for weekly replacement.

▶**Universal Winding Co.,** Providence 1, R. I., has acquired the business and personnel of Patterson, Moos and Co., Inc. The latter has been active in nuclear physics, electronics and ordnance engineering. The new division of Universal Winding will continue operations at 90-28 Van Wyck Expressway, Jamaica 18, N. Y.

▶**Fischer & Porter Co.,** Hatboro, Pa., has acquired patents and engineering personnel of Electrical Development Co., Inc., and Digi-Coder Corp. Fischer & Porter thus provides "package instrumentation" for plant and production control.

▶**National Cash Register Co.,** 3348 W. El Segundo Blvd., Hawthorne, Calif., has purchased remaining stock of Computer Research Corp. of California to make the company a wholly owned subsidiary. As an NCR division, it will manufacture electronic computers for business applications in addition to its present line of computers.

LITERATURE AVAILABLE

Production control spectrograph. Literature describes production control spectrograph, model MS-2. *Scientific Specialties Corp., Boston 35, Mass.* (L-1)

Computers. Brochure illustrates computers and plug-in components. *Servomechanisms, Inc., Westbury Div., Post & Stewart Aves., Westbury, N. Y.* (L-2)

Gage and valve combinations. Data sheet 238 shows variety of connections available with gages and valves. *Jerguson Gage & Valve Co., 80 Fellsway, Somerville, Mass.* (L-3)

Constant temperature baths. Bulletin No. 666 shows dual-purpose baths designed for utility and serological use.

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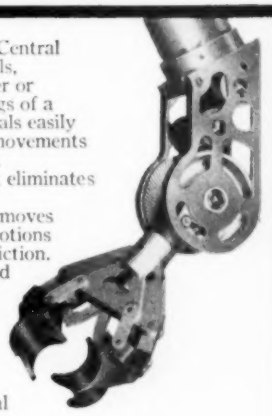

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Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill. (L-4)

Power supplies, regulators. Catalogue No. 254 describes a-c and d-c units. *Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn.* (L-5)

Atomic demonstrator. Booklet illustrates kit for construction of atom model as study aid. *Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.* (L-6)

Compressors and vacuum pumps. Bulletin 16BS126 describes air or gas handling compressors and vacuum pumps. *Allis-Chalmers Mfg. Co., Milwaukee 1, Wis.* (L-7)

Test equipment. Brochure describes electronic test equipment. *William Miller Instruments, Inc., 325 N. Halstead Ave., Pasadena 8, Calif.* (L-8)

Solenoid valves. Bulletin HP 201 describes high-pressure solenoid valves. *Atkomatic Valve Co., Dept. H-228, 545 Abbott St., Indianapolis 25, Ind.* (L-9)

Laboratory equipment. Bulletins 702 and 3500 and catalog describe labrooms, ovens and clamps, respectively. *Labline, Inc., 217 N. Desplaines St., Chicago 6, Ill.* (L-10)

Radiation instruments. Catalog No. G-12 shows line for monitoring, dosimetry, and isotope analysis. *Landswerk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif.* (L-11)

Diaphragm valves. Bulletin No. 15 describes acid, solvent and alkali proof diaphragm valves. *Maurice A. Knight, Kelly Ave., Akron 9, Ohio.* (L-12)

Thermal radiometers. Two types of model 188 portable thermal radiometers are described in leaflet. *Beckman & Whitley, Inc., 985 San Carlos Ave., San Carlos, Calif.* (L-13)

Radiation laboratory equipment. Catalog N illustrates equipment. *Nuclear Instrument & Chemical Corp., 223 W. Erie St., Chicago 10, Ill.* (L-14)

Radiochemicals. Catalog lists available carbon-14 labeled compounds. *Research Specialties Co., 1148 Walnut St., Berkeley 7, Calif.* (L-15)

Hydraulic valves. Catalog No. 260 describes solenoid-operated subplate-mounted hydraulic valves. *Rivett Lathe & Grinder, Inc., Brighton 35, Boston, Mass.* (L-16)

Tetrode and photo transistors. Bulletins give tentative specifications for type 700 tetrode transistor and type 800 phototransistor. *Texas Instruments, Inc., 6000 Lemmon Ave., Dallas 9, Texas.* (L-17)

Chemicals. Catalog lists chemicals for chemical, clinical, biological, bacteriological laboratories and industry. *Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.* (L-18)

Analog computers. "Evaluation Techniques for Electronic Analog Computers" discusses available computers and their technical capacities. *Beckman Instruments, Inc., 2200 Wright Ave., Richmond, Calif.* (L-19)

Solenoid valve. Bulletin 105 gives characteristics of series 4000 stainless-steel solenoid valves. *Atkomatic Valve Co. Inc. 545 W. Abbott St., Indianapolis 25, Ind.* (L-20)

Moisture indicator. Bulletin M.I. 100 describes "Little One Eye," moisture indicator for gas lines. *Pilotrol Corp., Box 172, Springfield, N. J.* (L-21)

Hydraulic pumps. Bulletin DP-302 describes PF-100 dual-vane hydraulic pumps. *The New York Air Brake Co., 1700 E. Nine Mile Rd., Hazel Park, Mich.* (L-22)

Regulated power supplies. Brochure illustrates line of regulated supplies. *Lambda Electronics Corp., 103-02 Northern Blvd., Corona 68, N. Y.* (L-23)

Closed-circuit television. Brochure describes and illustrates basic applications of "TV Eye," closed-circuit equipment. *Radio Corp. of America, Camden, N. J.* (L-24)

Laboratory power amplifier. Laboratory report No. 10 discusses laboratory power amplifier with negligible distortion and phase-shift compensation. *Technology Instrument Corp., 531 Main St., Acton, Mass.* (L-25)

Demineralizers. Bulletin WC-111 discusses demineralizing equipment. *Graver Water Conditioning Co., 216 W. 14th St., New York 11, N. Y.* (L-26)

Oscillograph. Brochure describes model 580 oscillograph. *Midwestern Geophysical Laboratory, 3401 S. Harvard, Tulsa, Okla.* (L-27)

Low-temperature apparatus. Catalog describes equipment for storage, transport and transfer of liquified gases. *Hofman Laboratories, Inc., 219-221 Emmet St., Newark, N. J.* (L-28)

Radiation instruments. Catalog gives line of radiation instruments for labo-

ratories, civil defense, universities, hospitals and industry. *Professional Instrument Corp., 149 Broadway, New York, N. Y.* (L-29)

AC voltmeter. Brochure describes transfer volt ammeter. *Charles Engelhard, Inc., 850 Passaic Ave., E. Newark, N. J.* (L-30)

Instrumentation magazine. Quarterly publication "Instrumentation" is available. *Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.* (L-31)

X-ray analysis. Four-page folder on X-ray diffraction for the evaluation of properties of metals is described for research and production. *North American Philips Co., Inc., Research and Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y.* (L-32)

High-frequency resistors. Bulletin F-3 describes miniature resistors. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (L-33)

Voltage dividers. Bulletin describes use of voltage dividers with electrometer to measure d-c potentials to 20,000 volts. *Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio.* (L-34)

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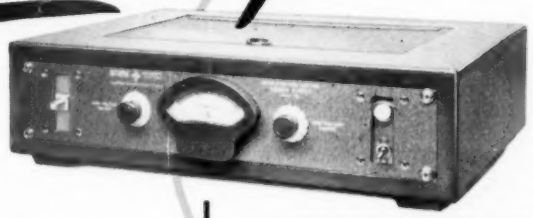

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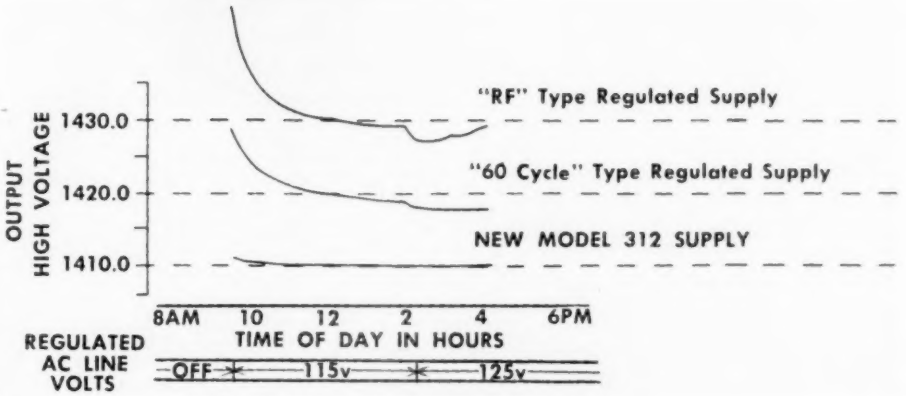

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